

1-1-2002

Investigating the use of ThinkerTools to promote learning of Newton's laws of motion among middle school students

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**Investigating the use of ThinkerTools to promote learning of Newton's laws of motion
among middle school students**

by

Han-Chin Liu

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE

Major: Education (Curriculum and Instructional Technology)

Program of Study Committee:
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2002

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This is to certify that the master's thesis of

Han-Chin Liu

has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy

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CHAPTER 1: INTRODUCTION

The purpose of this research was to investigate how the use of a computer program called “ThinkerTools” and its accompanying material influenced middle school students in learning concepts and principles of Newtonian motion. The research investigated how middle school students reacted to the ThinkerTools program, and how their use of ThinkerTools influenced their learning. In addition, the problems that students encountered while using ThinkerTools program were also identified.

Background

When students are learning scientific theories, they may lack experience with the phenomena those theories seek to explain. Traditional lectures and textbooks typically present abstract symbolic representations of scientific concepts or principles without providing sufficient experience with the phenomena with which the concept and principles are associated. As a result, students may find it difficult to understand the concepts and principles that make up the theories. In addition, some of the phenomena that scientific theories seek to explain are difficult for students to experience directly. In particular, students learning Newton’s laws of motion, commonly have difficulty understanding them. Students typically interpret and create their own model of motion according to their everyday experience. Some forces, such as friction from the air and the surface that a sliding object contacts, are invisible forces that affect the motion of an object. Because they are invisible, students may not perceive such forces. As a result, students typically construct conceptions to explain motion that are inconsistent with Newtonian principles.

Hands-on experiments are the primary activities in today's science classes designed to help students experience the phenomena that abstract theory tries to explain. However, because of the cost of the equipment and the complexity of conducting experiments in classrooms, many students receive insufficient hands-on learning experiences (Braun, 1972; Bloomer, 1974; Marks, 1982; Clariana, 1988). In addition, equipment that provides students with truly frictionless surfaces is impossible to construct. For these reasons, memorizing formulas and solving questions with equations typically become the main activities when students are learning Newton's laws of motion (White, 1983).

With the development of information technology, simulated environments can be created that allow students to experience the phenomena of interest. Using simulations as an instructional tool can be a solution for breaking the foregoing limits of hands-on experiment and, in addition, can offer a learning environment that is superior to those provided by traditional lectures and textbooks (Braun, 1972). As tools to facilitate hands-on experimentation, simulations should be given a larger role in the learning process to connect students with real-world experiences.

Today's computer technology can provide dynamic graphic animations and simulation experiences that can help students relate abstract content, such as mass, velocity, and acceleration to real experiences. Animated visuals can also provide explicit demonstrations that are not easy to observe with the naked eye. For example, on a computer screen, the trajectory of a moving object can be presented in dots that are left behind the object.

ThinkerTools was developed by White, Frederiksen, and their colleagues (1993). They have conducted a series of studies with ThinkerTools. ThinkerTools, a computer

simulation program produced collaboratively between the Graduate School of Education at University of California, Berkeley and the Educational Testing Service, simulates the motion of objects to which impulses are applied. ThinkerTools can simulate motion in an ideal frictionless and gravityless environment. In addition, mass, gravity, and friction can be applied and varied. ThinkerTools initially provides students with a frictionless environment in which motion is possible only along one dimension. Users can apply impulse forces (a short duration force like a kick) in horizontal or vertical directions to control the motion of dot on the screen. Users can use these impulse forces to control the direction of motion and the magnitude of the velocity to move a dot on the screen. They are given a graduated series of problems to complete (moving and accelerating horizontally, moving and stopping) to learn how applied impulses influence motion. As the level of the activity moves higher, the motion in two dimensions becomes possible and users have more control on the variables such as mass, friction, and gravity. The activities lead users to get familiar with the interface and build up their basic understanding of how impulses influence objects to produce motion and velocity. ThinkerTools encourages users to generate hypotheses and to design experiments to test their hypotheses. Data on motion can be collected by the computer and displayed in tabular or graphic for analysis. For example, users can modify the mass of the object. An object of one mass and another object of twice the mass can be created. Users can explore differences in the velocities of two objects of unequal mass when equal impulses are applied. ThinkerTools promotes the development of scientific theory implicitly. Newtonian physics is not explicitly presented, but the objects behave according to its principles. Students develop understanding of the concepts and principles of Newtonian physics by being asked to predict the outcomes of certain assigned situations and then completing the

activities. Then, the students "test" their hypotheses in depth, using pre-designed computerized models. In the end, the students compare their predictions with the outcomes they witness on the computer screen.

Since the whole ThinkerTools package includes detailed activities that guide students to explore the concepts and tries to cover most related principles of Newtonian motion, it demands a large amount of time for students to accomplish the tasks. In reality, middle school science teachers might want to use only parts of the package as the tool to facilitate student learning because of the curricular requirement and time constrain. They might also integrate additional activities according to their instructional goals. Students' benefits from using ThinkerTools program might be affected by partial use of ThinkerTools. In order to understand in depth how students benefit from using ThinkerTools program, further study investigating the interactions between student and the program, the problem students encounter, and their attitude toward the program is necessary.

This proposed research project was planned to investigate how middle school students interact with ThinkerTools and to explore how the use of limited portions of the ThinkerTools package might influence student learning. Positive attitude towards the software might promote better interactions with the software package during learning and therefore, motivate interest in learning. For that reason, attitudes and achievement, as well as direct observations of how students used the software were assessed in the present study. Students in middle school classes participated in a unit on motion that incorporated several of the ThinkerTools activities. The research was designed to:

1. explore, in depth, how students used ThinkerTools and to explore their use influenced their understanding of Newtonian motion and kinematics.

2. assess students' attitudinal reactions to the ThinkerTools software package as an instructional tool,
3. investigate students' reactions to, opinions about and attitudes toward the interface and navigation design of ThinkerTools, and to identify problems students encountered when interacting with the interface and navigating the software.

CHAPTER 2: LITERATURE REVIEW

Several researchers have examined the influence of animations and simulations on students' learning of science concepts and principles. In this section, a description of research on simulation is provided. Prior studies regarding students' conceptual change are also reviewed. Next, research investigating animations in science learning is reviewed and specific research on the effects of animations on the learning of the physics of motion is reviewed.

Nature of simulation

Graphics and animations have been used as instructional tools in education for years, especially in teaching science (Peters and Daiker, 1982; Rieber, 1991; Williamson and Abraham, 1995; Kelly, 1997; Khoo and Koh, 1998). According to Paivio's (1986) dual coding theory, information encoded in both visual and verbal formats is better remembered than that which is encoded in only one of these two formats. A variety of symbolic (numbers) and graphical information typically is used to try to explain scientific concepts to students. For example, arrows and lines are often used to represent the direction and magnitude of force. Additionally, the relationship among force, mass, and acceleration is usually represented in mathematical symbols and formulas such as $F=m*a$ when explaining Newton's second law of motion. Students with limited knowledge and experience have difficulty translating such descriptions into a conceptual understanding of the law (Gorsky & Finegold, 1992).

In simulations, reality is represented in a highly modified fashion in order to increase its accessibility for an individual's understanding (Dale, 1969). According to McGuire (1976), simulation is "placing the individual in a realistic setting where he is confronted by a problematic situation which requires his active participation in initiating and carrying through sequences of inquiries, decisions, and actions." Marks (1982) stated that computer simulations are considered to be tools valuable for allowing effects of changes to be seen in models before revoking the change in the real world. This promotes students' problem-solving skills. The incomplete information gained from simulations forces students to make decisions about the data for solving further problems. In addition, simulations can increase student enthusiasm and motivation by giving them the chance to explore the simulated environments and conduct simulated experiments without restriction. Some computer simulations have been shown to be effective in causing conceptual change (Zietsman & Hewson, 1986; Gorsky & Finegold, 1992; Weller, 1995).

Computer simulations can be combined with collaborative learning techniques. When students work in groups, they can discuss and argue their ideas. Computer simulations can provide a vehicle for productive student interactions (Krajcik, Simmons, & Lunnetta, 1988). Simulations allow students to rerun the program and come to agreement after reflecting on their ideas in group discussions. Communication requires students to reflect on and make explicit their conceptions. This interaction can contribute to conceptual change. Therefore, simulation-mediated conversation and interaction between students can facilitate conceptual development.

Simulated situations can provide anchors to facilitate learning. The Cognition & Technology Group at Vanderbilt has argued that students learn more effectively when their

instruction anchors learning in situations that are meaningful to the learner (Cognition & Technology Group at Vanderbilt: CTGV, 1990, 1993).

According to the CTGV (1993, p.52), anchored instruction consists of the following premises:

1. Learning and teaching activities should be designed around an “anchor” (or situation), which should be some sort of case study or problem situation.
2. Curriculum materials should allow exploration by the learner.

Computer simulations provide situations that allow exploration by students themselves. The learning/teaching simulation can be designed as activities that include a problem or issue that is of interest to the students.

Simulations in science education

Peters and Daiker (1982) tested the effect of graphics and animated instructional tools in introductory organic chemistry lessons. The objectives of the study were to determine whether the materials were effective and would contribute to student's learning. College students without prior chemistry knowledge who viewed animations with lecture in an introductory chemistry class were compared to students who received a regular lecture without animations. Students were tested on overall knowledge and knowledge related to the topics of the animations. In addition, students completed a questionnaire assessing students' attitudes toward using the simulations. Students who viewed animations gained more on the overall performance test than students who just received a lecture. From the questionnaire results, students responded positively toward the animated content. However, the result of the test of chemistry knowledge related to the specific topics of animations showed that students'

performance was not improved directly by the use of animated content. Therefore, Peters and Daiker reexamined first, the inferred instructional objectives, second, the questions related to the objectives, and third, the instructional sequences related to both the objectives and questions. They found that the animation had no measurable direct effect on test scores because the animation was not focused carefully enough on the objectives. Students' responses from informal interviewing also confirmed their suspicion. Peters and Daiker concluded that the animated materials needed to be carefully related to the objective and more interactive elements were also needed to draw students' attention to that concept.

Kelly (1997) created a computer program that showed scanned pictures of various minerals and that demonstrated their properties. Ninth grade earth science students who used this program were compared to students who examined real mineral examples in real life laboratory setting. Students were tested on their skills of identifying different structures of minerals and their basic knowledge about minerals. Although the researcher speculated that students who viewed computer-simulated pictures of minerals might not have had the chance to experience the mineral luster in a three dimensional view, no significant difference was found in the students' test performances. This research suggested that viewing scanned pictures provided an equivalent learning experience to hands-on manipulation, at least when assessed by these measures.

Williamson and Abraham (1995) studied students' ability to build mental models to visualize particulate behavior in matter. Many students do not understand the particulate nature of matter. Computer animation technology was used to build dynamic models with three-dimensional presentations. The animations worked as either visual aids in lecture or as a computer-simulated laboratory for assigned activities. College students who received

lecture accompanied by animations and lab simulations were compared to students who received lecture and lab animations and to students who received lecture only. Students were tested on logical thinking, understanding of chemistry concepts, and attitude toward the animations. No difference in logical thinking was found among the three groups. However, students who received the animation treatment performed better than those who received only lecture on the tests assessing understanding of the chemical concepts. These results also indicated that students in the control group held more misconceptions than those in treatment groups. The researchers concluded that computer animated models increased conceptual understanding of chemical phenomena because they demonstrated the processes of interaction among microscopic particles that are not easily visualized from verbal descriptions. Meanwhile, no difference was found between the use of animations in lecture and in lab activities. These latter results indicated that giving control to students made no difference beyond simply demonstrating the animations to students. However, the researchers argued that the simple, basic concepts covered by this study could be easily achieved by simply demonstrating animations to students.

In Khoo and Koh's (1998) study, college students were exposed to a simulated context that gave students control of rotating, making bonds, and changing the elemental atoms of a crystal structure in three dimensions. A questionnaire was given to collect students' feedback regarding their perception, their understanding of crystalline structure, their ability to visualize the concepts of molecular dynamics and crystal structures, and the students' attitudes toward the simulations. From the collected data, students were found to be highly interested in the three-dimensional graphic representation. After using the simulation software, students were found to rank themselves higher in their abilities of visualizing and

understanding the structure of molecules and crystals. Therefore, the researchers concluded that the use of animations made the visualization process easier. The simulations also seem to be more motivating for the students.

ChanLin and Chan (1996) investigated the effect of graphic representations and the use of graphic representations integrating metaphorical strategies for learning biotechnology. One hundred and twenty college students with lower level prior knowledge of biology were involved in the study. Six groups of students received treatments based on non-graphics, static graphics, and animated graphics either with metaphors or without metaphors. Metaphors were used in this study to try to improve the effects of the graphic representations and to emphasize the meaning of graphics in order to help students understand the concepts of biotechnology. A criterion-referenced test was used to assess students' performance and students' attitudinal responses were gathered using Keller's IMMS (Instructional Materials Motivational Survey). Students who received animation treatments with metaphors scored higher in both the criterion-referenced test and motivational response than students in the other groups. No significant difference was found among the non-metaphor graphical representation treatment groups (non-graphics, static graphics, and animated graphics). The researchers questioned whether students, without metaphors, could accurately interpret the graphic objects or animations on the screen. The results supported the hypothesis that using metaphors along with a scenario provided by an animation could help facilitate students' learning. The study concluded that metaphors could be used to make the visual representation more concrete to the learners.

In order to test the effect of scaffolding learning from simulations, Hmelo and Day (1999) compared first year college medical students who received cases provided by

simulations to students who received normal paper cases. The simulations generated questions in specific cases and asked the experimental group students for explanations, identifications, and predictions for the events or cases. Students in the control group received papers describing cases and tasks that were similar to the cases for experimental groups. Student log files of their interactions with the software were gathered. Data sources included videotaping, field notes, students' case summaries, explanations, and on-line notebooks. Students' explanations of the cases were used to examine the students' understanding of the scientific mechanisms. A questionnaire with open-ended questions was given to students to ask them to evaluate the contextualized questions and the software in terms of its educational value and usability. Students using simulations were found to include more critical observations and inferences in their case summaries and explanations than students using paper cases. The questionnaire results indicated that students responded positively toward using the simulations. The students' answers to the open-ended question also indicated that they liked having the control to make their own decisions. From students' responses, the researchers suggested that more time was needed for students to adjust to this new way of learning and that the software needed to provide more feedback to allow students to focus more completely on the learning processes.

Silverstein and Tamir (1993) examined the effect of using visual representation such as scientific symbols, schematic drawings (namely Documentary Code), and comic graphics in story-telling animations (namely Story Animation Code). The animations were compared to the use of verbal symbols on high school students' learning in the biological sciences. Tests examining the students' state of knowledge and misconceptions were used to assess student's achievement. In addition, Anthropomorphic Teleological Questionnaires (ATQ) for

subjects such as “The Cell” and “Birth” also were used to test students’ concepts in both situations. Students’ pretest to posttest gains were compared. The influence of independent variables was estimated and expressed by effect size. Frequency distributions were calculated for background and attitudes. Gains were found in both documentary code and story animation code conditions rather than in verbal code condition. This result indicated that visual representations led to a gain in learning. In addition, the story-telling comic graphics promoted a more positive attitude toward learning. There was a relative decrease in causal explanations in favor of anthropomorphism and teleology following the screening of the story animation in the topic of the Living Cell but not in the subject Birth. Also there was an increase in the number of causal statements following the screening of the story animation code. These results showed that the learning gain from story animation was also accompanied by the development of misconceptions because students were used to decoding visual stimulus with their prior experience. According to Blich (1989), the term “decoding” includes two processes: projection of the viewer’s prior knowledge on the visual message and filling-in of the picture being viewed using prior knowledge and perception. Students might apply their daily experiences into the decoding processes when receiving graphically represented information that is totally new to them.

Simulations as a vehicle to promote communication

When students work in pairs or teams, simulations provide opportunity for students to understand the significance of communication skills, teamwork and cooperation (Marks, 1982). Otero, Johnson, and Goldberg (1999) tried to explore the influence of two particular classroom structures: the computer document and computer simulations on students’ learning

of physics concepts. Science phobic college students worked in groups, shared computer documents, and used computers simulations to build and test models of their observed phenomena. The shared computer in this study was used to stimulate interactions about physical ideas and concepts and for all students to have a “shared conceptual space” to build explanatory models for phenomena observed from hands-on experience. Also it would be used as a simulator to build and test corresponding conceptual models. Qualitative data was gathered from videotaping, interviewing students, and field notes of students’ discussions. Otero et al. (1999) found that, when used socially, a computer can serve as a tool to structure communication between individuals about physical phenomena and concepts and also as a simulation that can help students construct a conceptual model of physical phenomena. In addition, students using model-like simulations performed similarly to the way they do when using hands-on experiments.

Carlsen and Andre (1992) explicitly combined the use of simulations with the use of text designed to produce conceptual change. They compared students in groups receiving conceptual change text with or without animations to students receiving traditional text with or without animations. College students, who had not taken college physics, studied simple electrical circuits and read one of the two texts. In the conceptual change text, students were given diagrams of possible circuits. Students were asked to predict what would happen in the circuit. These questions were given before students read explanations of the concept covered in the diagram and were designed to elicit students’ misconceptions. The control group read a traditional text that simply covered basic electricity concepts. In addition, to assess their predictions, students either simply read explanations of how circuits would work or constructed the circuits using a simulation and used the simulated circuit to test whether the

diagrammed circuit would function. A posttest designed to assess understanding of series circuits demonstrated that student who received conceptual change text scored higher than those who received traditional text. Additionally, students who used the simulations made more progress towards a more correct scientific understanding of circuits than did students who did not receive simulations. These results indicated that both the activation of misconceptions through the conceptual change text, and the active exploration involved in using the simulations to build circuits, helped students to change the prior conceptions and to create more scientifically acceptable conceptions.

Simulations and understanding principles of motion

Zietsman and Hewson (1986) investigated the effects of instruction using both microcomputer and conceptual change strategies. Tenth grade students and college freshman without prior knowledge of motion in physics used microcomputer simulations to learn the principles of motion. This group was compared to those who used the relative motion of real objects. The authors examined how remedial sequences of a computer program affected students, who were identified as holding alternative conceptions of velocity. To access their conceptions of velocity, students completed an apparatus diagnostic test accompanied by an unstructured interview and a simulated experiment on a microcomputer. The computer simulation was used as the posttest in all cases. The remedial sequences of the computer program were used as the treatment for experiment group. Students' responses (correct and incorrect) to the simulation were collected by the computer and analyzed qualitatively to see if the same conceptions identified by the real-world experiment also were identified by the simulations. Students, conceptions identified by the simulated tasks showed no difference to

the conceptions of velocity identified using real objects. Zietsman and Hewson concluded that microcomputer simulations provided the same effect on building students' scientific conceptions as the real world experiments. Students viewing remedial sequences of the simulation were more likely to make correct responses. This result indicated that the remedial sequences of the microcomputer program, which used a conceptual change strategy, helped students change their conceptions of velocity.

Weller (1995) conducted a similar study to investigate a microcomputer system for diagnosing and remedying students' alternative conceptions of force and motion. Eighth grade students, who had studied force and motion two or six months earlier, viewed computer simulations regarding force and motion and were compared to students who completed the test questions without experiencing the simulation. The students were ranked by their teachers according to their achievement in science class in order to determine whether any correlation existed between students' degree of science achievement and possession of their proceeding alternative conceptions. Questions on computer screen regarding force and motion were given to students to diagnose students' alternative conceptions. Posttests were also given to students via computer simulations. Students' responses to the questions posed by the computer were automatically saved to be analyzed. In addition, a delayed posttest was given one and half months later to seven students to test the duration that students held the scientific conceptions. In general, students in both groups scored higher on the posttest than on the pretest. Students held fewer alternative conceptions and more scientifically correct conceptions after the instruction. Students viewing computer simulations answered more of the posttest questions correctly than those in the control group. The immediate posttest results indicated that the computer simulations significantly helped

students alter their alternative conceptions in the short term. Five of the seven students who were given delayed posttest scored the same as they did on the immediate posttest, which showed the robustness of the conceptual change. No significant correlation was found between students' pretest score and teachers' ranking of students' science achievement, which indicated that strong learners also held alternative conceptions. Weller suggested that science teachers couldn't assume strong learners need not to be examined for alternative conceptions. Due to the positive results of the study, Weller suggested that a greater beneficial effect could be obtained if the diagnosis and remediation system were integrated into students' normal classroom context and allowed each student more control and choice to adjust it to match their own progress.

In Rieber's (1991) study of fourth grade students learning Newton's laws of motion, a group of students who received animated graphics were compared to students who received static graphics. The Newton's second law of motion was not taught directly to the students in either the animated graphics or static graphics conditions. In addition to the animation, the animated graphics condition demonstrated the second law without teaching it directly. The intent was to test the effect of using the animated simulation to improve incidental learning. A posttest was given to test students on their understanding of Newton's first and second laws of motion. Although it was not taught, two additional questions assessing students' understanding of gravity were added in the posttest. It was believed that the animation might lead to the development of misconceptions about gravity because the simulated environment was gravityless and frictionless. The gravity items were included in the posttest in order to test that hypothesis. At the end of this study, students were given three choices: answer more questions just for fun, spend more time in the structured simulation, or complete a word-find

puzzle on another topic. The purpose of this choice was to investigate students' continuing motivation to use the simulation. Students who received animated graphics were found to have higher scores than students who received static graphic on both understandings of Newton's first and second laws. The researcher concluded that the implicit use of simulation reduced cognitive load on the students and helped them acquire knowledge of the second law without explicit instruction. A higher percentage of students' first choose to spend more time on the simulation at the end of the study. This result indicated that the simulation motivated students in learning. However, students using simulation scored lower than students using static graphic on the questions regarding gravity. The researcher argued that the frictionless and gravityless simulation removed the effect of gravity and therefore allowed students to construct a misconception. The researcher suggested that more guidance would be needed to avoid having students construct such misconceptions when using simulations in teaching.

A positive effect of using simulations to help students understand abstract physics theories was found in studies, especially when the simulations was integrated with supporting strategies in the learning context (Rieber, 1990, 1995; Gorsky & Finegold, 1992; White, 1998; Andre et al., 1999). A well-designed strategy of incorporating simulations in instruction can enhance learning by improving the possibility of students' changing misconceptions.

Rieber (1990) compared fourth and fifth grade students who used animated graphics to those who used either static graphics or no graphic as visual elaborations in learning Newton's laws of motion. Three types of practices (answering multiple choice questions, practicing the simulations with more control, and no practice) were also used to compare the effects of different strategies accompanied by simulations. Students were tested on their ability to apply rules of force and motion. Students' attitude was also surveyed at the end of

the study. Students in simulated group performed better than those in the static graphic group. Students who received practice with controlling the simulations scored higher than students who received practice on answering multiple-choice questions. From significant interactions found in the results, the researcher concluded that animated graphics influenced student performance when practice was provided. However, this effect was eliminated without practice.

In Rieber's (1995) later study, fifth grade students who received structured simulation were compared to those who received unstructured simulation. Students in either group also received or did not receive a tutorial. Students were tested on performance, comprehension monitoring, and confidence while answering the posttest questions. The results indicated that students receiving a structured simulation scored higher than those who receiving an unstructured simulation. The result also indicated that students who received a tutorial performed better than students who received no tutorial when using simulations as learning tool. A tutorial was also found to promote increased students' confidence and comprehension in this study. However, the result showed that, even with the structured simulation, students failed to learn physical science without the tutorial. Rieber argued that novice learners without prior knowledge about the content might feel lost when using simulation without instruction. Therefore, the researcher suggested that learner guidance was needed to make learning strategies effective when using simulations in instruction.

Gorsky and Finegold (1992) used simulations to create dissonance between students' misconceptions and the simulated phenomena. Nine students from 9th to 12th grade in a rural high school were treated with animations to help them learn concepts of force. Seven out of nine students had not studied physics. Students completed a pretest in which they answered

questions regarding their conceptions of force and motion. Their pretest results indicated they held incorrect conceptions about forces. After they answered the questions, they viewed simulations that conflicted with their alternative conceptions of force and motion. For example, when students chose the answer “Friction is not a force”, an animation of a book continued to move along the table horizontally and did not come to rest. When students perceived the conflict between their prior conceptions and what they observed in the simulations, they could access a help system. The help system showed information designed to scaffold the students to reconstruct their understandings of force. The effects of the simulations were assessed through interviews and class observations. The qualitative results showed that students established correct conceptions about contact force and motion after viewing the unit. In this study, simulations were used to elicit students’ non-science concepts of force and to provide a framework for the acquisition of new concepts. Therefore, the researchers suggested that simulations needed to be used prior to formal classroom instruction and there should be more teacher involvement in helping students to construct new concepts

In the later paper containing two studies, Andre et al. (2000) tested the effects of using simulations before or after students read a physics text on students’ learning of Newton’s laws of motion. College students with little prior physics knowledge were given computer simulations that provided experiences consistent with Newton’s first law either before or after reading text that explained Newton’s first law of motion. A pretest was given to collect students’ prior knowledge of Newton’s first law of motion. The first study used a relatively primitive simulation done on the Apple II. The results of the first study showed that male students who viewed animations before reading text were found to gain a better

understanding of the first law than male students who received animations after reading text or control students who completed a non-Newtonian computer game. No effects were found for females. In the second study, a more sophisticated program for the Macintosh, called ThinkerTools, was used. The connection between the simulation and the subsequent text was made more explicit. In this latter study, both male and female college students, who used ThinkerTools prior to reading a text on the first law, did better on a posttest dealing with motion than did students in the control condition.

As the developers of ThinkerTools project, White and Frederiksen (1998) set up a curriculum that emphasized a metacognitive approach to instruction using an inquiry cycle (Question, Hypothesize, Investigate, Analyze, Model, and Evaluate). The researchers sought to enhance the teaching and learning of scientific inquiry. The instruction promoted a process called “reflective assessment” in which students reflected on themselves and each other's inquiries. Reflective assessment was expected to affect student learning of science inquiry. Classroom research communities of seventh, eighth, and ninth grade students were formed in the activities. During their learning activities, students were taught how to carry out scientific inquiry and discovered the basic physical principles for themselves by doing experiments. Therefore, students themselves constructed physical theories. In the process, students not only learned about physics, but also learned about the process of inquiry.

Evidence of the benefits and transfer in the subsequent work of ThinkerTools students was found. According to the results, ThinkerTools worked as a modeling tool to make the difficult subject of physics understandable as well as interesting to a wide range of students. Students using ThinkerTools in learning Newtonian mechanics were found to gain more than those in the control group who received traditional instruction. That finding also revealed that

the effect of ThinkerTools varied between grades. Students in lower grades without previous instruction on Newton's laws of motion outperformed those in higher grades who had more background knowledge received from traditional instruction. Significantly better performance was found when ThinkerTools software was accompanied with reflective assessment as the teaching strategy. In this study, reflective assessment was found to benefit students by improving social interactions believed to promote communication and collaborative learning. In addition, reflective assessment increased the understanding of science as well as the processes of inquiry (design and reasoning). An important finding in White and Frederiksen's (1998) study was that students who had lower standardized test achievement benefited more from the designed project activities than those who had higher standardized test achievement. This finding indicates that a simulated context accompanied with a well-designed teaching strategy reduced the difference of metacognitive expertise between lower and higher achieving students.

While the above research demonstrates that ThinkerTools can facilitate students' learning of motion, it did not entail an intensive investigation of *how* students utilized the ThinkerTools software. Additional research is needed to fully understand student's attitudinal reactions toward the design of ThinkerTools program and how they interact with the program in learning principles of Newtonian concepts. In addition, the ThinkerTools package is comprehensive and demands considerable instructional time. Because of curricular demands, many teachers may not be able to use the entire ThinkerTools package. How partial use of the ThinkerTools program benefits students in learning also needs further investigation.

CHAPTER 3: METHODOLOGY

Participants

Newtonian motion is a section included in 8th grade physical science in many Iowa communities. Therefore, the target population for this study was middle-school-age children in grade eight, typically 13 and 14 years old. A central Iowa middle school science teacher, who was enthusiastic about computer-assisted instruction in science education, volunteered her classes for this research study. A total of 102 participants were available in her five regular science classes. The teacher was willing to use ThinkerTools in the science classroom as a regular part of her class activities. Therefore, all of the students in the teacher's classes participated in the ThinkerTools activities. Informed consent forms were sent to both students and their parents. Both students and one parent had to agree to participate in the study for the student's information to be used. Researchers received agreement from 100 students and their parents.

Design

In order to answer the research questions, the study involved quantitative and qualitative methods. To assess the impact of the overall learning experience, students received a pretest and a posttest. In addition, the study involved an intensive examination of how a selected subset of students from each class used the software. Two pairs of students in each class were audio taped while they used ThinkerTools. In addition, the experimenter closely observed one pair of students and took intensive field notes about what they did.

Instructional materials

The activities used were selected by the classroom teacher from the teacher's guide to the ThinkerTools package. The ThinkerTools package consists of modules accompanied by hands-on experiments that students complete using the ThinkerTools package. The instructional materials pose guiding questions for the students and provide places to record data. The ThinkerTools modules were designed to allow students to vary components of motion and to lead students through a progressive set of experiences designed to help them question and change their prior ideas about motion and develop more scientifically accurate conceptions. The activities allow students to alter variables within the simulated environment to study their effect on the simulated motion of the dot on the screen. The ThinkerTools activities selected were as follows. The actual materials given to students are presented in screenshots in the accompanying file (TT module screenshots.pdf, see Appendix E).

Computer programs

Module 1: The Effect of Impulses in a One Dimensional World. (1.1 Speeding up, 1.2 Stopping, 1.3. Different velocities, 1.4 No end walls, 1.5 Going vertical, 1.6 Moving dots. (Programs in the "TT" folder of the accompanying CD-ROM, see Appendix E.)

Module 2: Modeling the Effect of Sliding Friction. (Set up the magnitude of friction and then observe the motion of the object. (Programs in the "TT" folder of the accompanying CD-ROM, see Appendix E.)

Module 3: Mass and the Effects of an Impulse. (Design of computer experiments) (Programs in the "TT" folder of the accompanying CD-ROM, see Appendix E.)

Module 4: The Effects of Impulses in Two Dimensions (4.1 Turn a corner, 4.2 Run in a maze, 4.4. Hit the target) (Programs in the “TT” folder of the accompanying CD-ROM, see Appendix E.)

Some of the modules asked students to change variables that might influence the motion of an object. In addition, activities that required students to generate hypotheses and to use ThinkerTools to test their hypotheses were included in the modules. There was homework and reading for each class activity. The homework was intended to help students explore basic physics concepts such as speed, velocity, acceleration, force, mass, and friction. The reading worked as supporting materials in which students could find answers when they encountered questions and provided information to resolve conflicts that originated in the students use of the ThinkerTools program. The readings were assigned right after each module activity. The readings were selected by the teacher from chapter one: "What Is Motion?" and chapter two: "The Nature of Forces" of the textbook: "Motion, Forces, and Energy" (Maton et al., 1997). The reading and homework activities were designed to help students construct their knowledge of motion and to prepare for the next activities in using ThinkerTools. Hands-on experiments were integrated among the ThinkerTools activities. The hands-on experiments were planned to elicit students' understanding of concepts such as acceleration, speed, velocity, and force. Four students were randomly chosen from each class section. Their conversation during the class time was audio taped in order to study their use of ThinkerTools and their reactions toward it. At the end of the activities using ThinkerTools, two students were chosen to be interviewed from each class. During the interview, students were asked to describe their feelings about and use of ThinkerTools (see Appendix C). A

posttest was given to investigate students' understanding about Newtonian motion after these activities.

Equipment

The classroom was set up with 11 Apple PowerBook laptop computers before the activity began. The ThinkerTools program and the files needed for the different modules were installed on each computer. Two Macintosh desktop computers with the ThinkerTools program and the necessary module files installed were ready in the classroom on a backup basis. Student booklets containing the directions and worksheets for each activity were handed out to students prior to the activity. Homework and in-class feedback questions were included in the booklets as well as the instructions for using ThinkerTools to build models. Additional instructions informing students about particular activities were handed out during the class activities. The materials handed out to students are presented as the files: Introduction printouts.pdf and Homework.pdf in the accompanying CD-ROM (see Appendix E).

Instruments

Pretest

The pretest consisted of 17 questions selected from the assessment booklet that came with the ThinkerTools program. The assessment booklet was developed by White and Frederiksen (1993). The questions were selected from the "TT Physics Test" and "General Physics Test" sections. Four questions were selected from the "TT Physics Test" section in order to test students' understanding of force and motion. These questions tested how

students associated the speed with the position of an object at fixed time interval (dot print). Also, the length and direction of arrows were used in these questions to test students' ability to infer magnitude and direction of impulse. Thirteen questions selected from the "General Physics Test" were based on students' everyday experiences regarding force and motion. These questions were intended to assess students' prior conceptions regarding force and motion with graphics representing balls, the motion of rockets, and boats in a real world situation. Examples of the pretest are presented in appendix C.

Student homework

Student homework papers from all class sections were collected and copied. Homework was chosen from the "ThinkerTools II Student Research Books", which is part of the ThinkerTools package booklets. Questions that used the basic graphics used in ThinkerTools, such as the dot print and the data cross, were included in student homework. Some of the homework questions asked students to predict the results when an object was in different situations. Also, part of students' homework required students to analyze the data they collected from ThinkerTools activities and to draw conclusion from the results. The homework provides an assessment of students' understanding of the first law as they progressed through the unit. The student homework activities are presented in file: Homework.pdf in the accompanying CD-ROM (see Appendix E).

Attitude and reaction questionnaire

Each student completed a questionnaire (see Appendix A) containing 16 questions that asked about their attitudes toward and reactions to using ThinkerTools. Responses were rated on a 1 – *very untrue of me* to 5 – *very true of me* scale. The questionnaire included 3

items about the instruction provided by the software. Six items asked about the control, navigation, and interface of ThinkerTools. Three items asked about their conceptual conflict and the extent to which they connected the ThinkerTools experiences with real world experiences. Two items asked about their understanding regarding Newtonian mechanics. The remaining two items asked about their interest in using ThinkerTools. Seven open-ended questions (see Appendix B) accompanied the questionnaire asked students about their feelings about using ThinkerTools and how they believe that ThinkerTools facilitates learning Newton's laws of motion.

Posttest questions

Questions regarding concepts of motion and force were used for the posttest (see Posttest Questions.pdf in the accompanying CD-ROM, Appendix E). The posttest questions were chosen from a variety of sources. Some of the questions came directly from the Assessment part of ThinkerTools booklets package. Others came from 8th grade materials such as Motion Forces and Energy (Prentice Hall), Physical Science (Glencoe), and Science Insights - Exploring matter and Energy (Scott Foresman). Sixteen multiple-choice questions and 43 completion questions were used as the posttest questions to test students understanding from preceding the activities. Twenty-seven out of 59 questions needed students to describe their understanding of motion and force. The rest of the questions asked students to calculate and obtain the answers for concepts such as acceleration, force, and momentum.

Procedure

The instructional unit and assessments occupied 14 days of class time. The pretest was given a week before the ThinkerTools session began. The teacher used the pretest to begin the unit. After the pretest session the teacher began instruction on motion. The timetable below outlines the day-by-day activities followed during the 14 days of the unit.

(The first week)

Day 1: Pretest

The pretest was given to students in order to test their prior understanding of Newton's laws of motion.

(The second week)

Day 2 – Day 3: The ThinkerTools activities begin

The students had double period classes. The teacher opened the class by asking the students to predict the result of a moving ball on a frictionless surface that was hit by a bonker. After they made their prediction, the students began ThinkerTools. They completed computer activities 1.1 to 1.6 in Module 1 from the ThinkerTools materials (see, Homework.pdf in the accompanying CD-ROM, see Appendix E).

Students used the simulation, observed motions and recorded their findings. Next, students answered the questions in their booklet as assigned homework. The questions tested students' understanding of velocity and speed that were represented in dot print and footprints.

Day 4: Discussion

Students (the whole class) and the teacher discussed the homework from Day 2 and Day 3 (Homework 1, see file: Homework.pdf in the accompanying CD-ROM, see Appendix E).

After the discussion, students needed to answer questions regarding the magnitude of velocities represented in data cross and dot prints.

Day 5: Modules 4.1,4.2, and 4.4,motion in two directions and Module 2, motion under sliding friction

There were two computer activities in the first part. In the first activity (Modules 4.1 and 4.2), student tried to implement their homework plans by having the dot travel in: (1) a rectangular path and (2) a diagonal path. In Module 4.4, students set up both horizontal and vertical impulses and then released the dot to hit the target with the required resultant velocity.

In Module 2 activity, students examined the motion of the dot under the effect of sliding friction.

(The third week)

Day 6 – Day 10: Hands-on experience

Students completed the following:

- Pulling a card resting on a cup from under coin resting on the card.
- Spinning a raw egg and a hard boiled egg.
- Pulling the tablecloth out from under the china.
- Blowing through a straw at a ping-pong ball to change velocity.
- Measuring acceleration for a ball rolling down a ramp.

Also the teacher did a demonstration of projectile motion and an activity in which the kids rolled a marble around an aluminum plate that had a pie piece cut out and observing which way the marble went.

(The fourth week)

Day 11- 12: Modules 2 and 3. Mass and the Effects of an Impulse (Design of Computer Experiments)

During the class activities, students wrote their hypothesis regarding the relationship between mass and velocity of a moving object. Next they set up the variables of mass and friction in ThinkerTools. Students examined the data derived from their computer experiments and made conclusions about their hypothesis from their observation.

(The fifth week)

Day 13: Interview (ThinkerTools was not used)

Two students were interviewed from each class session. Ten students total were interviewed from the five class sessions. Students were interviewed with questions regarding their attitude toward ThinkerTools and physics. In addition, two of the interview questions were printouts of ThinkerTools scenarios. Students were asked to describe how they accomplished the tasks by using ThinkerTools.

Day 14: Project presentations

Students in groups presented their conclusions from their computer experiment and their understandings of mass and force.

Day 15: Posttest

A posttest was given to students after they finish the unit.

Data analysis

Classroom observations, student homework, interviews, questionnaire, pretest, and posttest measures were used to assess outcomes. Audio taped class observation and audio taped interview answers were transcribed. The transcribed data and in-class field notes were categorized. Categorizing and refining categories will be repeated until patterns and themes were identified. In doing this, I grouped the student data to provide answers to my research questions such as “*How students interacted with ThinkerTools*” and “*What their attitudes are toward ThinkerTools*”. In order to examine how individual students developed their science inquiry skills during the class activities, student homework was investigated. Student’s homework answers were coded and compared against their pretest answers and classroom observations to attempt to understand the process of an individual’s conceptual change.

Quantitative analysis was performed on student responses to questionnaire items about the ThinkerTools package. This analysis was designed to summarize student reactions toward using ThinkerTools package. In addition, quantitative analysis of student performance on parallel pretest and posttest items were completed.

CHAPTER 4: RESULTS AND DISCUSSION

Thirty-five students were selected from the 100 available participants. This sample included the twenty students (10 groups, two groups of four students in each class) that were audio taped during their activities and fifteen additional students that were randomly selected from each class (three in each class). My first research purpose was to explore how students used the ThinkerTools package and to explore how their use influenced their understanding of kinematics. In order to understand how the ThinkerTools package might influence the student's understanding of motion, it is important to understand their initial conceptions about motion. The pretest provided 17 items that provided insight into students' understanding of kinematics. In the following section, I describe how their understanding was revealed by the pretest. On each of the pretest items, students selected or wrote a response and provided a written explanation for their response. In all cases, I classified student responses as correct or incorrect. I also classified student explanations as correct or incorrect. I analyzed the nature of the students' incorrect explanations. Therefore, student answers were classified into the following categories: correct answer with correct explanation, correct answer with incorrect explanation, incorrect answer with correct explanation, and incorrect answer with incorrect explanation. A table was used to indicate these categories if there was space in the item for students to express their interpretation. In scoring explanations as correct or incorrect, I ignored grammatical and spelling errors and interpreted what the students wrote as correct if the underlying meaning they were expressing seemed to capture the essence of the correct idea. For example, in Question 1 below, the student's written explanation was scored as correct because it seems to indicate that ball that

is closer to the floor, will travel less distance and take less time to reach the floor. The inaccuracies in the students' expression of that idea (it has less time to travel, it goes through the floor) were ignored. The students' ability to express their ideas in correct language was weak.

Pretest (students' understanding of force and motion)

The teacher labeled the pretest items. The first four items were named Item 1, Item 10, Item 11, and Item 13; the rest of the items were named Question 1, Question 2, etc. (see Pretest Questions.pdf in the accompanying CD-ROM, Appendix E). This labeling scheme is used below to refer to the pretest items.

Dot prints representing the motion of an object (Items 1, 10, and 11)

Student answers. As shown in Table 1 three pretest items (Items 1, 10, and 11) presented students with possible dot prints and asked students to indicate which set of dot prints best represented the motion of the object. A dot print is a mark left on the screen by the moving dot. While students were taking the test the teacher explained to students that the dot prints were “dropped” at a constant rate (e.g., one per second). The three items represented the motion of an object that was accelerating or speeding up along its line of motion, an object that had received an initial push and was sliding across a surface that had friction, and an object that was falling in a gravitational field (see Pretest Questions.pdf in the accompanying CD-ROM, Appendix E, Items 1, 10, and 11). To answer the question correctly, students had to both select the correct alternative (visual representation) and be able to represent their understanding in their written explanation. In addition, the explanation needed to match the

visual representation they selected. A classification of student answers, answer frequencies, and typical answers can be found in Table 1.

Table 1 shows that, on the pretest, about 45 percent of the students chose the correct set of dot prints for the accelerating (Item 1) and motion with friction (Item 10) items. These students typically gave a reasonably correct explanation of what was happening in the situation. In both of these items, the dot's motion was represented horizontally on the page.

Table 1. Students' explanations for the motions expressed by dot prints (n=35)
(Lines with an * are lines in which the student's response and explanation is correct.)

Answer	Sample explanation	Count (%)
Item 1. Speeding up		
.	Note: there is no place for students to write their explanation for their answer in this question.	0 (0)
.		20 (57)
*		15 (43)
Item 10. Motion with friction		
.	Because it could have the same amount of push and kept constant unless you pushed it again.	2 (6)
*	It would start out faster because it was given an impulse but then it would slow down because of the friction.	13 (37)
.	Because when you first push the dot it is going fast and then it slows down more and more.	17 (49)
Item 11. Free falling		
.	It would make these printing because it is not being pushed right or left and friction is not changing their speed so they would all be the same	13 (37)
.	When something is dropping from a high distance, it gains more speed at the end	15 (43)
.	Because as an object drops it continues to increase its speed the more air time it has because of gravity.	7 (20)
* .		

Interestingly, when the horizontal motion was changed to vertical motion as in Item 11, only about 20 percent of the students were able to identify the correct dot prints and provide reasonable explanations. Apparently the shift from horizontal to vertical motion made the problem substantially more difficult.

Even more interesting, in Items 10 and 11, many students verbally described the motion of the dot correctly, but picked the wrong answer on the three items (6, 17% in Item 10 and 11, 31% in Item 11; see Table 2). This pattern of correct explanation and wrong dot print selection shows that more than one third of the students did not seem to be able to translate their verbal representation of motion into a visual representation. This finding raises questions about both the validity of the test questions and about the nature of the students' understanding. A true understanding of speeding up and slowing down would lead to equal comprehension of the dot prints if the students attended to all the information given. However, many students might not have attended and might have impulsively selected an answer. Based on their everyday experience, the students probably knew that friction would slow down a moving object or that an object that was speeding up would move faster and faster. They could describe these changes in motion in words. However, when the motion was represented by dot prints, the students had difficulty relating their experience-based knowledge and verbal representation to the dot prints. From their answers, we found that students often interpreted the frequency of dot prints per unit distance as a measure of the dot's velocity (57% in Item 1, 49% in Item 10, and 43% in Item 11). The results suggest that students had problems relating the distance/time relationship to the motion of an object.

Table 2. Student answer and explanation classification (n=35)

Count (%)		Examples of explanations
Item 10		
Correct answer + correct explanation	13 (37)	<ul style="list-style-type: none"> Because the dots get wider apart and then they get close toward the end. if it begins to stop, the dots will get closer together, because it is slowing down, and the last dot will show where it stopped. Because the friction on the ground on the ball would eventually stop it. It is being pushed at the beginning with the most speed, the friction then drag it down to a stop.
Correct answer + incorrect explanation	2 (6)	<ul style="list-style-type: none"> Cause the dot almost hit each other. Because it's constant and then the impulse to the right takes it faster.
Incorrect answer + correct explanation	6 (17)	<ul style="list-style-type: none"> Because when you first push the dot it is going fast and then it slows down more and more. The dot starts off fast then friction slows it down. It would start out faster because it was given an impulse but then it would slow down because of the friction. Friction slows things down.
Incorrect answer + incorrect explanation	14 (40)	<ul style="list-style-type: none"> Because the dots get farther apart to the right Because you give it an impulse, I don't think dot will go faster or slower. The dots got an impulse which spreads the dots more. Because when you give the impulses, the dots will speed up.
Item 11		
Correct answer + correct explanation	7 (20)	<ul style="list-style-type: none"> Starts at slow but then speed up toward the ground. It would gain speed as it falls Because it would move faster and faster it move down because of the gravity. Because the gravity will speed it up, that 's what C is showing happening.
Correct answer + incorrect explanation	0 (0)	
Incorrect answer + correct explanation	11 (31)	<ul style="list-style-type: none"> When something is dropping from a high distance, it gains more speed at the end. Gravity pulls down, so it will go down with more speed as it gets pulled by gravity. If there is no friction then it wouldn't slow down. As the ball drops it increases velocity and speed. The dot starts out slow but it gains speed falling until it hit the floor.
Incorrect answer + incorrect explanation	17 (49)	<ul style="list-style-type: none"> Because it is pulled down only, it will fall at a steady rate, without much variation. Therefore, the dots will be the same distance apart. If there was no friction the ball would fall constantly. Because the dots are the same space apart. It's speed couldn't change.

Falling object with horizontal impulses

A series of items on the pretest related to student understanding of bodies falling in a gravitational field and how horizontally applied impulses combined with the vertically applied impulse of gravity to influence motion. The student responses to these items revealed a number of problems in student understanding of these situations.

Item 13. Student answers. This pretest item asked students to predict the motion of two dots starting at the same height that were then given different impulses to the right and released simultaneously. The item required students to predict which dot would hit the ground first. A classification of student answers, answer frequencies, and typical answers is found in Table 3.

Only 6 out of the 35 students (17%) picked the correct answer, and only 5 out of the 35 students provided reasonable explanations (Table 4). Twelve (34%) students who chose “a” as their answer explained that the dot hit with more impulses would spend more time traveling in the air and would therefore hit the ground later (34%). In contrast, five (14%) students who chose “b” as their answer explained that the dot hit with more impulses would

Table 3. Students’ prediction about the motion of the two objects (n=35)
(Lines with an * are lines in which the student’s response and explanation are correct.)


Item 13. Horizontal motion with gravity		
		
Answer	Count (%)	Sample explanation
The dot given one impulse to the right.	21 (60)	Because the first dot is given only one impulse to the right, it has a more direct path to the floor. The 2nd dot has to curve more to the right and then hit the floor.
The dot given three impulses to the right.	8 (23)	Because it is given 3 so it’s traveling faster so the 3 impulses will stop faster than just 1 impulse.
*Both dots would hit the floor at the same time.	5 (14)	Because no matter how large the impulse, with gravity, the dots would fall at the same time.

Table 4. Student answer and explanation classification (n=35)

	Count (%)	Examples of explanations
Item 13		
Correct answer + correct explanation	5 (14)	<ul style="list-style-type: none"> ▪ Because no matter how large the impulse, with gravity, the dots would fall at the same time. ▪ Because the gravity will cause them to fall at the same rate. ▪ Since object will always hit the ground at the same time. ▪ It would not matter if you push it to the right, it will fall at nearly the same speed.
Correct answer + incorrect explanation	1 (3)	Note: the only student in this category left the explanation blank.
Incorrect answer + correct explanation	0 (0)	<ul style="list-style-type: none"> ▪ Because when you first push the dot it is going fast and then it slows down more and more. ▪ The dot starts off fast then friction slows it down. ▪ It would start out faster because it was given an impulse but then it would slow down because of the friction. ▪ Friction slows things down.
Incorrect answer + incorrect explanation	29 (83)	<ul style="list-style-type: none"> ▪ Because it wouldn't have to go to the right as much, it would just go a little then go down. ▪ If it is pushed more, it will go farther like throwing a ball. The one to the right has less impulses so it won't go as far and hit the floor sooner. ▪ The dot with three impulses is going forward instead of down but the other is going faster down than forward. ▪ It doesn't have as much speed, so the gravity would pull it down quicker than the other one.

move faster to hit the ground. These cases indicated the possibility that, without real life experience, students had difficulty understanding a falling object with horizontal impulses.

Question 1, Question 3, Question 5


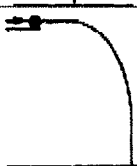
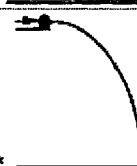
Student answers. Question 1 showed students two identical balls dropped simultaneously from different heights. Students were required to predict which ball would hit the floor first and to give a written explanation. Some students chose the correct answer, but did not explain correctly because they believed that the dots would travel at the same speed, but that the lower one would have less distance to gain speed. Seven students (20%) who chose the wrong answer explained that the higher dot would eventually gain more speed and catch up with the lower dot (Table 5). In the second part of the question, students were asked

to make a prediction about the speeds of the dots when they hit the floor. Some of the students chose the correct answer, but they also believed that the higher dot had more gravity and would hit the floor with higher speed.

Question 3 showed possible trajectories of a ball that was kicked off a cliff. Students needed to select the correct trajectory and explain their reasoning. Twenty-one (60%) students chose the correct answer, demonstrating their understanding of the motion affected by gravity and inertia (Table 5). Some of the students (12, 34%) who picked incorrect answer B explained that the momentum affected the dot so the dot briefly moved straight and then it fell to the ground in a curved line.

Question 5 is similar to Item 13. Students had to make a prediction about two identical balls hit from the edge of a table with different impulses. Only three students chose the correct answer and only two students explained correctly (Table 6). This question tested student understanding on the same concepts as in Item 13. Only two students answered and explained this question correctly, suggesting that composing and decomposing forces and velocities challenged student understanding. Furthermore, fewer students explained and answered correctly for Question 5 than in Item 13. The difference in the level of performance on Item 13 (17% correct) and Question 5 (9% correct) is not large, suggesting that the form of the question, as well as the students' understanding of kinematics, plays a role in their performance. Perhaps the verbal descriptive nature of Question 5, as contrasted to the visual presentation in Item 13, created difficulty because of the need to visualize the phenomenon. In any case, it is clear that most of the students (Question 5, 71%; Item 13, 60%) held the misconception that the ball that was hit harder would take longer to hit the floor because its forward momentum would interact with or temporarily overcome or partially reduce the

Table 5. Students' prediction about the motion with gravity (n=35)
(Lines with an * are lines in which the student's response and explanation are correct.)

Answer	Sample explanation	Count (%)
Question 1. Free falling of two balls at different height		
Part I: Which ball will hit the floor first?)		
*The lower ball	It is closer to the ground so it has less time to travel through floor	27 (77)
The higher ball	The higher on will speed up because it has more room to gather speed, then catch up with ball A.	2 (6)
Both balls hit the floor at the same time	The higher ball will pick up speed and hit the same time.	6 (17)
Part II: Which ball is going faster when it hits the floor?)		
The lower ball		0 (0)
*The higher ball	Because it has farther to go and will pick up more velocity and speed.	32 (91)
Both balls are going the same speed when they hit the floor.	They fall at the same speed.	1 (3)
Question 3. Trajectory of a ball kicked off a cliff		
	Because the gravity on the ball will push the ball straight down and it will not make a curve.	2 (6)
	The ball goes for a second because of the force behind it. Then it drops away in a curve to the ground because it is still gaining speed so can't go straight down.	12 (34)
	Just as the ball is first kicked off the cliff, the force of gravity will start to act on it. This force combined with the horizontal force will produce a curve path of the ball before it hit the ground.	21 (60)
Question 5. Two identical balls hit off the edge of a table with different impulses at the same time.		
The ball that you hit (hard)	The ball that was hit hard because it will have more energy stored up from being hit harder so when it falls it will fall faster.	7 (20)
The ball that your friend hit (less hard)	Since you hit the ball harder, the ball will take longer to hit the ground because it is moving forward more than it is down so your friend's ball can descend faster.	26 (74)
*Both balls hit the ground at the same time	Because the force on the ball will be the same that will make them hit the ground at the same time.	0 (0)

gravitational force. These students typically perceived the longer path that the object hit with more impulse would take and may have believed that the longer path would imply greater travel time. Interestingly, on both Item 13 and Question 5, several students believed that the greater speed caused by the greater impulse would lead to the object to fall faster.

Table 6. Student answer and explanation classification (n=35)

	Count (%)	Examples of explanations
Question 1 Part 1		
Correct answer + correct explanation	27 (77)	<ul style="list-style-type: none"> ▪ Since the lower ball is closer to the floor and the same gravity is pulling the balls down ▪ There is less distance for it to fall, they are identical with no force pushing on it. They fall at the same speed. ▪ Because the lower ball is closer to the ground. ▪ A has less distance to travel.
Correct answer + incorrect explanation	0 (0)	
Incorrect answer + correct explanation	0 (0)	
Incorrect answer + incorrect explanation	8 (23)	<ul style="list-style-type: none"> ▪ B will have a higher gravity pull so they will both end up hitting at the same time. ▪ The higher ball will pick up speed and hit the same time. ▪ More gravity is on ball B so they will hit at the same time. ▪ Because the higher ball is going faster.
Question 1 Part 2		
Correct answer + correct explanation	32 (91)	<ul style="list-style-type: none"> ▪ The higher ball can gain more speed with more distance because the gravity is pulling down on it. ▪ It is higher up and has more time to travel. ▪ it will have fallen longer so its velocity is higher because it has gained speed while falling. ▪ Because it has more time to pick up speed.
Correct answer + incorrect explanation	2 (6)	<ul style="list-style-type: none"> ▪ Because there is more gravitational pull on the higher ball so it will be traveling faster. ▪ B is higher, so more gravity is being applied than A, so B will be traveling at a higher speed.
Incorrect answer + correct explanation	0 (0)	
Incorrect answer + incorrect explanation	1 (3)	<ul style="list-style-type: none"> ▪ They fall at the same speed.

Table 6. (Continued)

	Count (%)	Examples of explanations
Question 3		
Correct answer + correct explanation	21 (60)	<ul style="list-style-type: none"> ▪ Gravity will pull the ball evenly from the moment it leave the side of the cliff, and C depicts this. ▪ After it is off the ground gravity immediately pulls it down. ▪ Because once you kick it, it goes out and curves with gravity pulling it. ▪ Because when you kick the ball, it is going to gradually go down until it hit the ground.
Correct answer + incorrect explanation	0 (0)	
Incorrect answer + correct explanation	0 (0)	
Incorrect answer + incorrect explanation	14 (40)	<ul style="list-style-type: none"> ▪ Because when you kick a ball it goes straight and when this ball would keep going straight, it will finally realize that nothing is on it so then it will fall at a curve down to the ground. ▪ It depends if you hit the ball or less hard. ▪ Because when you start out, it will go straight because of the energy of the kick, then after that energy's gone, it will start to drop in a curve, but not too much of it. ▪ The ball would go straight off at first because of the power from the kick but then in it would curve out of that and fall to the ground
Question 5		
Correct answer + correct explanation	0 (0)	
Correct answer + incorrect explanation	3 (9)	<ul style="list-style-type: none"> ▪ Because the force on the ball will be the same which will make them hit the ground at the same time. ▪ The hard hit ball would travel farther to one side and less downward. The less hard hit ball could travel more down than over, but couldn't it have the same speed. ▪ If one is hit harder, it will go farther, but its excess speed will take it that far in the time it takes for the other ball to hit ground as well.
Incorrect answer + correct explanation	0 (0)	
Incorrect answer + incorrect explanation	32 (91)	<ul style="list-style-type: none"> ▪ The ball hit harder will move forward longer before falling straight down. ▪ Because the ball that you hit hard will have much more energy so it will fall to the ground faster than the one with not as much energy. ▪ Because the one that is going faster will go more farther out and gravity will pull the other dot down faster. ▪ Because the hard one has more force horizontally, the other one is going straight down.

Understanding Newton's First law of motion (see Pretest Questions.pdf in the accompanying CD-ROM, Appendix E, Question 2, Question 4, Question 9)

Student answers. Question 2 asked students to predict and explain the speed of a spaceship as it moved along while coasting in deep space. Most of the students (86%) appeared to understand the coasting spaceship in space and answered/explained correctly (Tables 7 and 8). The result shows that most of the students could visualize the motion in outer space. However, the question itself might have provided prompts by suggesting that the spaceship was “coasting” so the students could relate their everyday experience to answer the question.

Question 4 required students to predict the landing point of a ball dropped by a running person. Seven (20%) students did not consider the effect of inertia and believed that the ball would fall straight to the bucket (answer B) (Table 7). Some students who chose the correct answer did not explain their answer reasonably because they believed that the ball would bounce and then fall into the bucket. This response still could be considered to be correct because students referred to the concept of inertia in their explanation for the movement of the ball.

Question 9 required students to predict the path of a ball that was just traveling out of a “C” shape tube. Only 38% of the students answered correctly and provided a reasonable explanation (Table 8). Their explanations suggested that most of the students understood that the dot would move according to inertia. However, they could not identify what affected the inertia of the ball.

Table 7. Students' prediction about motion in Newton's first law of motion (n=35)
(Lines with an * are lines in which the student's response and explanation are correct.)

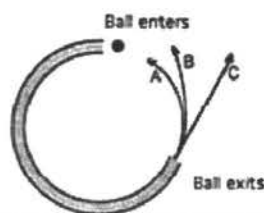
Answer	Count (%)	Sample explanation
Question 2. Coasting spaceship in deep space		
The speed will decrease.	3 (9)	Nothing to propel it.
* The speed will remain the same.	29 (83)	It will remain the same because there is no other objects gravity to affect it and since space is a vacuum there are no air currents to make it going slower or faster.
The speed will increase.	2 (5)	Because there are no forces pulling the spaceship toward anything so it will increase because there is no force pulling it in another direction.

Question 4. Dropping ball



*A	22 (63)	Drop before the bucket because since you are running your body will keep moving and the ball will keep moving (A body in motion stays in motion) so it needs to be dropped before the bucket to get in.
B	7 (20)	I think this is right because when you drop something it will go right down. You want to drop the ball to the bucket at point B because it shouldn't go too far away.
C	4 (11)	Because while you are running when you drop the ball it will force person on the ball and it will move backward.

Question 9. Ball traveling out of a "C" shape tube



A	11 (31)	I choose A because it will move in a circle when in the tube so it would keep the direction when it left the tube
B	11 (31)	The ball exits at B because there is still a little centripetal force on the ball so it still curves a little, but not all of the original force.
*C	11 (31)	I think the ball will just go straight out of the tube because it will not have anything that would guide it back around the circle like the other two choices say.

Table 8. Student answer and explanation classification (n=35)

	Count (%)	Examples of explanations
Question 2		
Correct answer + correct explanation	29 (83)	<ul style="list-style-type: none"> There is nothing around to increase or decrease the speed of the spaceship so it stays at the same speed. It should remain the same speed since it is coasting and is not affected by outside forces. It will remain the same because there is no other objects gravity to effect it and since space is a vacuum there is no air currents to make it going slower or faster. In space there is no gravity or wind or air so there is nothing to push or move the ship or stop the ship so once it's going, it won't stop without help.
Correct answer + incorrect explanation	1 (3)	<ul style="list-style-type: none"> I don't know.
Incorrect answer + correct explanation	2 (5)	<ul style="list-style-type: none"> Nothing to propel it. Because there is no planets to pull the spaceship in with its gravity.
Incorrect answer + incorrect explanation	3 (9)	<ul style="list-style-type: none"> Because in space there is no gravity and that makes everything slower, so as you move deeper in to the space, the slower the spaceship goes. Because there are no forces pulling the spaceship toward anything so it will increase because there is no force pulling it in another direction. Because the spaceship is in one place some time and it can be not near any planets.
Question 4		
Correct answer + correct explanation	22 (63)	<ul style="list-style-type: none"> Because the ball will roll off your hand and will hit or land in the bucket like the ball off the cliff. Inertia would keep it in the air. The ball will still go in the direction you are going. If you drop it after the bucket or right at the bucket, you will miss. If you let go of it while you are moving it will continue to move forward not drop straight down.
Correct answer + incorrect explanation	2 (6)	<ul style="list-style-type: none"> Because when you are running and then drop the ball, gravity will pull it down and a little further. I think drop the ball before bucket. Because you drop before the bucket, as you pass the air push the ball into the bucket.
Incorrect answer + correct explanation	0 (0)	
Incorrect answer + incorrect explanation	11 (31)	<ul style="list-style-type: none"> You should drop the ball just past the bucket because it will travel backwards. The force against the ball would force the ball backwards, but not much, so one would want to drop the ball almost at the bucket but just a few inches past. Because while you are running when you drop the ball it will force person on the ball and it will move backward. There are no force so gravity will bring it straight down.

Table 8. (Continued)

	Count (%)	Examples of explanations
Question 9		
Correct answer + correct explanation	11 (31)	<ul style="list-style-type: none"> ▪ The only thing keeping the ball from going straight in the first place is the tube, so since it exits, it will continue at that straight path. ▪ Right when the ball exits the tube, there is no longer a force that constricts it to a "curved motion". It then will go straight. ▪ When the ball comes out, it has no force pushing it around so it goes straight. ▪ after the ball leave the tube it isn't hindered by the tube so it goes straight out.
Correct answer + incorrect explanation	2 (6)	<ul style="list-style-type: none"> ▪ Either Einstein or Newton's law of motion say so. ▪ The ball would follow the path of least energy excelled. Turning or curving would use energy.
Incorrect answer + correct explanation	0 (0)	
Incorrect answer + incorrect explanation	22 (63)	<ul style="list-style-type: none"> ▪ Because the ball is going faster when going in the tube, so it would keep going in a circular motion. ▪ I choose A because it will move in a circle when in the tube so it would keep the direction when it left the tube. ▪ The tube is curved and it forces the ball right around in the circle by the shape. ▪ The ball exits at B because there is still a little centripital force on the ball so it still curves a little, but not all of the original

Understanding Newton's second law of motion (Question14, Question1)

Student answers. Question 14 described two balls with different masses (a striped ball is four times the weight of a white ball) that were hit at the same time with same impulses and direction. Students were required to predict which ball had higher speed after the hit. Most of the students (71%) selected the correct answer (Table 9) and provided reasonable explanations probably indicating that they had more prior experience regarding this situation.

There were two parts to Question 15. The first part asked students to predict the distances of two identical pucks after they were hit with the same sized hit. One (black) puck moved on a smooth surface without friction, while the other (gray) moved on an unsmooth

surface. Most of the students (83%) chose the correct answer (Table 9), again probably indicating that they have had more real-life experience on this topic (sliding friction).

The second part of the question asked students to predict the speeds of the two pucks one second after the pucks were hit. This question was not difficult for students; however, three of the students had different interpretations of the question and chose answer A. They believed that the puck that moved on the smooth surface would reach the end of the smooth surface earlier and then slow down faster because it reached the unsmooth surface.

Table 9. Motion in Newton's second law of motion (n=35)

(Lines with an * are lines in which the student's response and explanation are correct.)

Answer	Count (%)	Sample explanation
Question 14. Effect of mass on motion		
<hr/>		
The striped ball (heavier) will have the higher speed.	5 (14)	Because it has more weight to keep it moving.
* The white ball (lighter) will have the higher speed.	25 (71)	The lighter weight of the white ball would make it go faster than the heavy striped ball.
Both balls will have the same speed.	2 (6)	Because they were hit with the same force so they will stay at the same speed.
Question 15. Effect of friction on motion (Part I)		
* The black puck will go the furthest.	29 (83)	Because it's lighter while the other one has more weight that will slow it down.
The gray puck will go the furthest.	1 (3)	It needs friction to slide.
The pucks will go the same distance.	1 (3)	C, cause then both have an advantage and both have a disadvantage so they would be the same
Question 15. Effect of friction on motion (Part II)		
The black puck will have the lower speed.	3 (9)	Because the force that hit it doesn't last that long, so it will start to slow down.
*The gray puck will have the lower speed.	26 (74)	Friction and the unsmooth surface will slow it down.
The pucks have the same speed.	3 (9)	The friction will not have taken effect yet.

Table 10. Student answer and explanation classification (n=35)

	Count (%)	Examples of explanations
Question 14		
Correct answer + correct explanation	25 (71)	<ul style="list-style-type: none"> Because the striped ball is four times the weight of the white ball. Because it has less weight and will be more affected by the hit. It is lighter so it will move faster. It will be able to get a faster start since it is lighter and easier to move.
Correct answer + incorrect explanation	3 (9)	<ul style="list-style-type: none"> It has less friction than the #4. The white ball will be going at a faster speed because it has a lower density than the striped ball. There will be less friction opposing it. The heavier ball will create more friction on the floor, slowing it down.
Incorrect answer + correct explanation	0 (0)	
Incorrect answer + incorrect explanation	7 (20)	<ul style="list-style-type: none"> Because of the weight the ball will go farther and faster than the white one. Because it is heavier and will speed up faster until it is going fast. Since the striped ball has more mass, it's speed will start out slower but then build up. Because they were hit with the same force so they will stay at the same speed.
Question 15 Part I		
Correct answer + correct explanation	29 (83)	<ul style="list-style-type: none"> Because friction slows an object down making the other go faster. Because it has smooth surface. It has no friction to slow it down. Without friction, there is no force that will be slowing the ball down.
Correct answer + incorrect explanation	4 (11)	<ul style="list-style-type: none"> It has nothing to slow it down beside gravity. The gray one has more particles to slow it down. It will have less friction on the puck, so it could be slowed as much by that. (The student did not explain the reason.)
Incorrect answer + correct explanation	0 (0)	
Incorrect answer + incorrect explanation	2 (6)	<ul style="list-style-type: none"> C, cause then both have an advantage and both have a disadvantage so they would be the same. It needs friction to slide.
Question 15 Part II		
Correct answer + correct explanation	26 (74)	<ul style="list-style-type: none"> The friction would slow the gray puck down. Since friction is opposing the gray puck, it will be slowed down. Because of the unsmooth surface it goes slower. It has more friction to stop it.
Correct answer + incorrect explanation	3 (9)	<ul style="list-style-type: none"> One second after, the friction acting on the gray will slow it so it will be going faster then the frictionless black puck. Right away the puck hits the bumps and friction, while the black one continues on the smooth surface. (The student did not explain the reason.)
Incorrect answer + correct explanation	0 (0)	
Incorrect answer + incorrect explanation	6 (17)	<ul style="list-style-type: none"> Because the sudden burst of speed is gone, which was the main cause of speed. Because the force that hit it doesn't last that long, so it will start to slow down. The friction will not have taken effect yet. The variables will not have kicked in yet.

Understanding Newton's third law of motion (Question 7)

Student answers. There were two parts to this question. The first part asked students whether there was any force (and its direction) exerted on a static black ball when a moving white ball hit it. Both balls had the same mass. Because the scenario indicated that the black ball was moving after being hit, students could easily indicate that there was force exerted on the ball that was hit. Therefore, most of the students (89%) answered this part of the question correctly (Table 11).

The second part of the question asked students if there was any force (and its direction) exerted from the static (black) ball to the moving (white) ball. When compared to the first part of this question, the findings suggest that some of the students (37%) had difficulty understanding whether there was any force exerted on a static object after being hit by another object (Table 11). More than one third of the students chose answer C because they thought that the force was “transferred” from the white ball to the black ball. A few students believed that because the white ball stopped, there was no force exerted on the white ball.

The impact of forces from different directions (Question 8,

Question 10, Question 12, and Question 13)

Student answers. Question 8 described two identical boats that were trying to cross rivers. Boat A was trying to cross a river with flowing current, while boat B was trying to cross a river without current. The two rivers were the same width. Students were required to predict which boat reached the other side first. Only four students identified that the force/velocity pushing the boat across the river was the same, indicating that most of the students (88%) had difficulty understanding the concept of composition/decomposition of

Table 11. Motion in Newton's third law of motion (n=35)

(Lines with an * are lines in which the student's response and explanation are correct.)

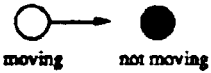
Answer	Count (%)	Sample explanation
Question 7 Hitting balls		
Part I. Does the white ball exert a force on the black ball?		
		
*Yes	34 (97)	
No	1 (3)	
Question 7 Hitting balls		
Part II. In which direction does this force act on the black ball?		
*To the right	30 (86)	Because the white ball is moving right direction when the white hit the black ball all the force are hit on the black ball, so the white ball stop moving.
To the left	4 (11)	When the white ball exerts the force on the black ball, that what makes the black ball move. The force on the black ball moves to the left and makes the white one stop.
There is no force acting on the black ball	0 (0)	
Question 7 Hitting balls		
Part III. Does the black ball exert a force on the white ball?		
*Yes	22 (63)	
No	13 (37)	
Question 7 Hitting balls		
Part IV. In which direction does this force act on the black ball?		
*To the right	2 (6)	The black ball exerts the force of the white ball to the right, because the white ball already exerts the force of the black ball to the left.
To the left	16 (46)	It exerts a force to the left causing a counter force action, which makes the white ball stand still
There is no force acting on the black ball	13 (37)	Because the white ball is giving the force to the black ball making it move.

Table 12. Student answer and explanation classification (n=35)

	Count (%)	Examples of explanations
Question 7, Part II		
Correct answer + correct explanation	30 (86)	<ul style="list-style-type: none"> As it moves along colliding with the black it hit the ball transferring its energy. Because when you hit the 2 balls the white ball give force on the black ball causing the white ball to stop and the black ball to go. When the black move to the right , it showed the force exert on the black ball. The force from the white ball hit the black ball the black ball moves but stops the white ball.
Correct answer + incorrect explanation	1 (3)	(The student left the explanation blank.)
Incorrect answer + correct explanation	0 (0)	
Incorrect answer + incorrect explanation	4 (11)	<ul style="list-style-type: none"> The white ball exert force on the black ball because the black ball, before collision, has force to the left and right and when the white ball hit the black ball, the white ball exert the left force on the black ball and moves to the right. When the white ball exerts the force on the black ball that what makes the black ball move. The force on the black ball moves to the left and makes the white one stop. When the 2 balls hit, the white ball is forced back or stay still while the black ball continue on. The white ball exerts force because the person that hit the ball had force that carried on to the black ball. The force on the black ball is to the left because that's where it got hit from.
Question 7 Part IV		
Correct answer + correct explanation	16 (46)	<ul style="list-style-type: none"> It exerts a force to the left causing a counter force action, which makes the white ball stand still. The weight of the black ball tries to keep it from moving but the white ball has much more energy. Because that's what makes the white ball stop moving. To the left because that makes it stop moving. When the white ball hit the black ball it stops because the black ball exerts force on the left side of the ball stopping the ball.
Correct answer + incorrect explanation	4 (11)	<ul style="list-style-type: none"> Everything has stored up energy. There has to be a force on the white ball because the white ball stops in its place. The force is to the left because that is the site the black ball is on. (The students left the explanation blank.) (The students left the explanation blank.)
Incorrect answer + correct explanation	1 (3)	<ul style="list-style-type: none"> 1. Because the white ball is giving the force to the black ball making it move.
Incorrect answer + incorrect explanation	14 (40)	<ul style="list-style-type: none"> The black ball exerts the force of the white ball to the right, because the white ball already exerts the force of the black ball to the left. The black was not moving and thus does not have a force. The black ball isn't moving stopping the white ball. This showed no force exert on the white ball. The white ball would have moved if there was pressure forced on it instead of stopping.

forces/velocities (Table 13). There were 26 students who indicated that the straight line across the river is a shorter distance for the boat to travel.

Question 10 required students to predict the path of a coasting rocket after its engine was turned on for a short time. Only ten students chose the correct answer, and only eight could explain their answer reasonably (Table 13, Table 14). Thirteen students, or approximately one third of the students, chose answer C. These students were aware that the momentum of the ship would combine with the force of the thruster to determine the path, but did not seem to realize that a curved path would require a continually acting force.

Question 12 asked students to predict the directions of impulses needed for an ice hockey puck to travel along two turns of a track. Again many students had difficulty integrating the momentum of the puck with the force to be applied. For the first turn of the track, only nine students (26%) took the momentum of the puck into account in selecting their answer (Table 13). Most of the students (74%) elected to hit the puck in the direction it should go. This scenario was possibly more common in students' prior experience and also made the students choose answer A.¹ Only one student chose the correct answer for the impulse in the second turn of the track, however, he did not clearly state the reasoning for his answer. Most of the students related their interpretation of the motion in the first turn to the explanation for the second turn. However, eight out of the nine students who chose the correct answer for the first turn chose the wrong answer (B) for the second turn. These cases

¹ In the real world, the mass of the puck is quite small relative to the force that the player can apply. When a large force is applied to the puck, it is possible that the puck will move approximately towards the direction of the force applied. In other words, if the momentum vector is a very small fraction of the impulse vector, the resultant direction of motion may be visually indiscriminate from the direction of the impulse vector.

showed that students had difficulty understanding the effects of momentum, especially when the object was not moving in a direct way.

Question 13 asked students to choose the correct path of a hockey puck that was hit by impulses in a different direction than the direction it was moving. This item tested students on the same concepts as the second part of Question 12. Only six students chose the correct answer C for this question, again showing that most of the students had difficulty integrating the momentum of the puck and the impulse applied (Table 13).

The pretest results suggest that many students have little understanding of kinematics. These results were not unexpected. The students were middle school students who were

Table 13. Motion under the impact of forces (n=35)

(Lines with an * are lines in which the student's response and explanation are correct.)

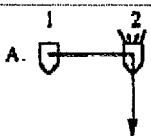
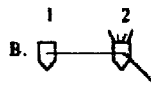
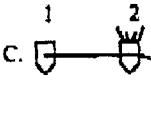
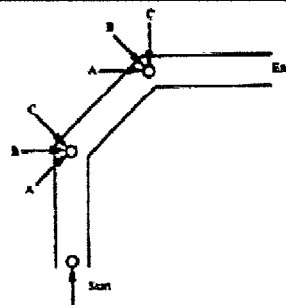
Answer	Count (%)	Sample explanation
Question 8. Boats across rivers (Which boat gets to the other side first?)		
The one crossing the flowing river (Boat A)	5 (14)	As boat A is drifting it is also pushing him down stream and towards the other side faster than the boat with no current.
The one crossing the still river (Boat B).	26 (74)	The one with no current because it can take the most direct route without a current pushing it downstream and taking a longer time.
* Both boats get to the other side at the same time.	3 (9)	
Question 10. The path of a rocket.		
 A.	14 (40)	Because the force on the rocket is going to push it straight down.
 * B.	7 (20)	The ship has momentum going sideways so when it tries to go forward it goes diagonal.
 C.	13 (37)	When the rocket engine is turned on, it will push down, but it's still going side ways, this results in a compromise of going both over and down in a curve.

Table 13. (Continued)

Question 12. An ice hockey traveling along the track

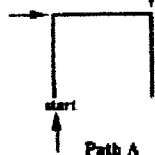


Answer	Count (%)	Sample explanation
Part I. The first turn		
A	26 (74)	Arrow A is pointing in the direction that the ball should be going.
*B	9 (26)	Because at that point, that would be where the puck might hit the wall.
C	0 (0)	
Part II. The second turn		
A	27 (77)	Because it points straight towards the end it will go straight.
B	7 (20)	It's still going up so if it's not hit a little down, it will hit a wall. The angle at which B hits will also take the puck to finish
*C	0 (0)	Because that could be where the dot would hit the wall.

Question 13. The path of an ice hockey puck

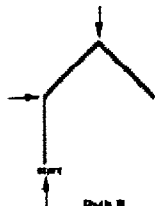
(No place for students to write their explanation in this question)

12 (34)



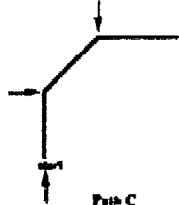
Path A

17 (49)



Path B

6 (17)



Path C

Table 14. Student answer and explanation classification (n=35)

	Count (%)	Examples of explanations
Question 8		
Correct answer + correct explanation	3 (9)	<ul style="list-style-type: none"> Both boats are going forward with the same force so they reach the other shore at the same time. The boat A isn't pointed in its direction so the river is the only force pushing it right so it reaches at the same time. Both boats posses the same forward force, so they will both end at the same time. The current processes its own force separately, which accounts for the resulted momentum of A. Both boats are moving at the same speed across the river, but one is being pushed a little downstream.
Correct answer + incorrect explanation	1 (3)	<ul style="list-style-type: none"> They both do because it is the same distance across.
Incorrect answer + correct explanation	0 (0)	
Incorrect answer + incorrect explanation	31 (88)	<ul style="list-style-type: none"> Because the shortest distance between a point is a straight line and the boat A wastes all the time going diagonally. There is not current pulling it sideways it goes straight the other one cannot. Because going straight is faster than going at an angle. Because the current flowing in the boat A don't permit to cross the river so fast and push the boat to the right.
Question 10		
Correct answer + correct explanation	7 (20)	<ul style="list-style-type: none"> Because even though it's going sideways, it moves straight ways too, so that makes it diagonal. Since the rocket was drifting in one direction already, the burst should only push it forward in this direction. If the burst is short and there is no gravity, the rocket would travel off in both down and right Because the rocket still has force from coasting.
Correct answer + incorrect explanation	1 (3)	<ul style="list-style-type: none"> Because when some thing falls it want to falls at a slant so I think that b would be the best.
Incorrect answer + correct explanation	0 (0)	
Incorrect answer + incorrect explanation	27 (77)	<ul style="list-style-type: none"> It would take a while for the rocket to start going straight after it had been traveling sideways. Because the rocket turns on its engine, but there is more force that it already has and not the engine. Because the force of the burst is much more than the coasting. It would go straight because the force of the engine would be greater than the force of outer space.

Table 14. (Continued)

Question 12, Part I		
Correct answer + correct explanation	9 (26)	<ul style="list-style-type: none"> ▪ It pushes to the right while it is traveling upward resulting a combo of direction. ▪ So it mixed with the starting hit and turns into the hit of 2. ▪ If they hit on B, the puck will go down the path with both forces going. If it is hit on A, it will still go forward a little and hit the wall. ▪ It is already heading up, so hit a could make it too far up. B could take the puck over and the start hit could still carry up.
Correct answer + incorrect explanation	0 (0)	
Incorrect answer + correct explanation	0 (0)	
Incorrect answer + incorrect explanation	26 (74)	<ul style="list-style-type: none"> ▪ Because then it would point in the direction that it needs to go. ▪ Because the ball could turn to the right in the curve. ▪ Because it is in the direction of the track. ▪ Because if you hit it, it need to go diagonally in the track.
Question 12, Part II		
Correct answer + correct explanation	0 (0)	<ul style="list-style-type: none"> ▪ Because that could be where the dot would hit the wall.
Correct answer + incorrect explanation	1 (3)	
Incorrect answer + correct explanation	0 (0)	
Incorrect answer + incorrect explanation	34 (97)	<ul style="list-style-type: none"> ▪ Because it points straight towards the end it will go straight. ▪ Because then it will go straight the end. ▪ Arrow A is pointing in the direction that the ball should be going. ▪ Because A is parallel to the side.

unlikely to have studied kinematics in any systematic way prior to this class. Their ideas about motion had to be based on their everyday experiences in which the decompositional analyses of Newtonian physics cannot be experienced directly (e.g., frictionless surfaces, gravity-free environments). As would be expected, the ideas about motion that the students

revealed are consistent with alternative conceptions identified by other researchers (Zietsman & Hewson, 1986; Gorsky & Finegold, 1992; Weller, 1995).

Some of the major alternative conceptions identified in this analysis of the pretest data are:

1. Students interpreted the frequency of dot prints per unit distance as a measure of the dot's velocity.
2. When an object was released with a horizontal impulse, students typically perceived the object would take a longer path to hit the ground and may have believed that the longer path would imply greater travel time.
3. Students believed that there is no force exerted by an object when the object is static.
4. The force needed to change the direction of an object's movement must be parallel to the desired direction.

The pretest data provide a baseline for comparing the students' performance during their use of the ThinkerTools package and on the posttest.

Homework

Using footprints to present an object's velocity, as it is moving. (Homework 1,













Homework.pdf in the accompanying CD-ROM, see Appendix E)

Student answers. Students had to accomplish Homework 1 before the Module 1 activity. There were three post-instructional questions for this homework. The first two questions asked students to describe the velocity and motion of a person from the footprints that the person left behind. The teacher considered 13 student answers incorrect because they

did not point out the change in the distances between footprints (Table 15). However, all of the students realized that the person's motion in this question was speeding up when the motion was described in footprints. According to my scoring, more students (26) provided reasonable explanations for the second question. However, students who did not answer correctly apparently did not state the relationship between time and the distance between footprints. The footprint questions were more understandable to the students possibly because students had more everyday experiences with footprint ideas. The questions reminded students of the person's speed. The questions connected students' experiences on footprints to the dot print idea.

The third question required students to draw a footprint pattern and tell a story from the footprint pattern they drew. Most of the students had no difficulty describing the motion of an object. These questions allowed students to relate their real-life experience to the concepts of motion represented in visual diagrams.

Table 15. Using footprints to present an object's velocity, as it is moving (n=35)

Answer	Count (%)	Sample explanation
Describe the velocity of the person who made these footprints		
		     
Correct	22 (63)	First it's going slow then is going faster or first are small steps then the steps are increasing the distance between each other.
Incorrect	13 (37)	The person gained velocity the more steps he took.
Describe the motion of the person who made these footprints		
		     
Correct	26 (74)	They are starting out walking but then they start to jump because the footprints are right next to each other.
Incorrect	9 (26)	They are fast and then just stopped.

Dot print analysis of a ball's motion (Homework 2)

Student answers. Students answered Homework 2 questions after the Module 1 activities. The answers for both Homework 1 and 2 were discussed in the next science class period. In this activity, the teacher showed a videotape of a billiard ball being bonked on a table in two situations: hit by one bonk and hit by two consecutive bonks. Students needed to measure the distances between dot prints that were printed on the handout and then record the distances in a table. The first part (one bonk) was a simple observational experiment and all of the 35 students could answer correctly and explain reasonably.

Some (11) of the students revealed interesting alternative conceptions about the second bonk in part two of the experiment (Table 16). They were confused by the second bonk because it was the same size as the first bonk. Therefore, they believed that it was just the same impulse applied to the ball and that its velocity would stay the same after the second bonk was applied.

Table 16. Dotprint analysis of a ball's motion (n=35)

Answer	Count (%)	Sample explanation
One-bonk experiment		
		• • • • •
Sample of Student's discovery: The velocity stayed the same after just one bonk.		
Correct	35 (100)	The velocity remained the same because only one bonk was given and there were no other forces that slowed or speeded it up.
Incorrect	0 (0)	
Two-bonk experiment		
		• • • • •
Correct	29 (83)	The ball's velocity speed up and the dot prints become farther apart
Incorrect	6 (17)	It stayed the same.
Correct	24 (66)	Because more force was added after the second bonk, making the velocity increase.
Incorrect	11 (34)	It was given the same force again.

Applying models (Homework 3, Homework.pdf in the accompanying
CD-ROM, see Appendix E)


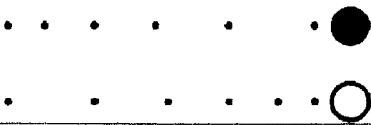
Data cross questions

Student answers. Students answered Homework 3 questions after they finished the third day activity (watching a demonstration of a ball's motion, measuring the distance of the dot prints left by the dot). There were three parts to this homework. The first part consisted of three data cross questions (Question 1 through Question 3). The first two questions required students to identify the directions and magnitude of the velocities of objects. Students were asked to draw a bar to indicate a dot's motion with the horizontal velocity of +4. Students answered Homework 3 questions during the next science class period after the Module 1 activities. Then, Homework 3 answers were discussed in the next science class period. Upon examination of student answers, all of the students answered the questions correctly, showing that students realized the velocities represented by the data cross. Because all the students answered the questions correctly and students were not required to explain their answers, no table is used here to present students' answers.

Dot print questions

Student answers (Table 17). There were two dot print questions (Question 3 and Question 4) in the second part of the homework. Students were required to identify which dot was going faster or was speeding up from the dot prints that were left behind. From the results and their explanations, there were 4 students who still held alternative conceptions about dot prints because they counted the frequency of the dot prints as the velocity of the dot. However, when compared to the answers for Item 1, Item 10, and Item 11 of pretest, there was improvement in the understanding of the concept of dot prints. In these pretest

Table 17. Applying models part I (n=35)
(The correct answer is indicated with a “*” sign.)

Answer	Count (%)	Sample explanation
Question 3. Which dot is going faster, the black dot or the white dot? 		
*White	31 (89)	The white dot is going faster because the dot prints are more spread apart.
Black	4 (11)	Because the more dot prints the more you press the button the faster it goes the faster it goes the higher the velocity.
Question 4. Which dot is speeding up, the black dot or the white dot? 		
White	4 (11)	Because it starts out slow because the prints are farther apart and then they get closer together.
*Black	31 (89)	Because when the dot prints spread out more, it means it's going faster.


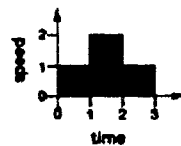
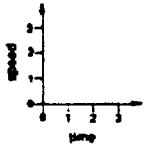
items, less than 43 percent of the students answered and explained correctly (Table 1). In Question 3 and Question 4 of Homework 3, 89% of the students could answer correctly and provide reasonable explanations (Table 17).

Computer model questions

Student answers (Table 18). There were five questions (Questions 5-9) in this part of the student homework. Question 5 asked students to describe in words and draw a diagram to illustrate what would happen to a dot when it was hit by impulses from different directions. Some (8) students might have had difficulty visualizing the descriptive nature of this question, and therefore answered the question incorrectly.

Question 6 asked students to measure the distances of a set of dot prints and fill in its data table. Question 7 required students to draw dot prints from a given data table. No significant errors were found in student answers for both these questions.

Table 18. Applying models part II (n=35)

Answer	Count (%)	Sample explanation								
Question 5. A dot is stopped. Then you give the dot an impulse to the right. Then you give the dot another impulse to the right. Next, you give it an impulse to the left. Then, you give another impulse to the left.										
Correct	27 (77)	The dot moves at one impulse so it is at positive one then it gets another impulse so it is at positive 2. Then it is given a negative impulse in the other direction so it is a 1. Then it is given one more negative impulse so it stops.								
Incorrect	8 (23)	It would roll forward, speed up, and then go back, moving backward at a constant speed.								
Question 6. Look at the dot prints . . . for a dot that is moving to the right and leaving one dot print per second. Then fill in its data table.										
										
		<table><tr><th>Time (sec)</th><th>Distance (cm)</th></tr><tr><td>0 to 1 sec.</td><td></td></tr><tr><td>1 to 2 sec.</td><td></td></tr><tr><td>2 to 3 sec.</td><td></td></tr></table>	Time (sec)	Distance (cm)	0 to 1 sec.		1 to 2 sec.		2 to 3 sec.	
Time (sec)	Distance (cm)									
0 to 1 sec.										
1 to 2 sec.										
2 to 3 sec.										
Correct	35 (100)									
Incorrect	0 (0)									
Question 7. Draw the dot prints according to the data table.										
		<table><tr><th>Time (sec)</th><th>Distance (cm)</th></tr><tr><td>0 to 1 sec.</td><td>1</td></tr><tr><td>1 to 2 sec.</td><td>2</td></tr><tr><td>2 to 3 sec.</td><td>3</td></tr></table>	Time (sec)	Distance (cm)	0 to 1 sec.	1	1 to 2 sec.	2	2 to 3 sec.	3
Time (sec)	Distance (cm)									
0 to 1 sec.	1									
1 to 2 sec.	2									
2 to 3 sec.	3									
Correct	32 (91)									
Incorrect	3 (9)									
Question 8. Look at the graph and show the impulse sequence.										
										
Correct	23 (66)									
Incorrect	12 (34)									
Question 9. Fill in the graph to show the speed of the dot as time passes.										
		<p>Suppose that you give a stopped dot an impulse to the right, then one second later you give another impulse to the right, and then one second later you give yet another impulse to the right.</p> 								
Correct	28 (80)									
Incorrect	7 (20)									

Questions 8 and 9 were graphing questions testing students' understanding of the velocity of a dot over time expressed in the form of a graph. Question 8 gave students a speed-time graph and asked students to describe the sequence of impulses applied to the dot. Question 9 described in words the impulses given to a dot and asked students to fill in the graph to show the speed of the dot as time passed. There was no space for students to write an explanation; therefore, the responses showed only their graphs. More students (12, 34%) provided incorrect descriptions for Question 8 than in Question 9 (7, 20%) showing that it was harder for students to interpret an object's velocity from a graph than to translate a verbally descriptive message into graphs.

Applying laws (Homework 4, Homework.pdf in the accompanying

CD-ROM, see Appendix E)

Student answers (Table 19). There were six questions in this homework. Homework 4 questions were assigned after Modules 4.1, 4.2, and 4.4 (Motion in Two Directions) activities. The answers were discussed in the next science class period. The first question asked students to think of and draw a sequence of impulses according to two given paths. The second and third questions challenged students to think of ways to reverse the sequence given in Question 1. Students had to draw the path according to the description and mark data crosses for each impulse indicated in the question.

Question 4 gave students an empty data cross and a target. Students were asked to fill in the stored impulses needed to hit the target. Students used a data cross and a descriptive paragraph in Question 6 to fill in the impulses and draw a target that would be hit by the dot. In this question, 28 students knew how to hit the target with impulses (impulses) in different

Table 19. Applying laws (n=35)



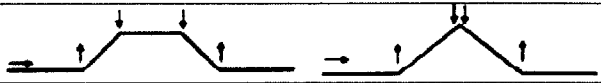

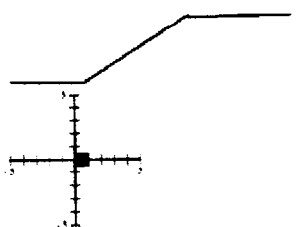
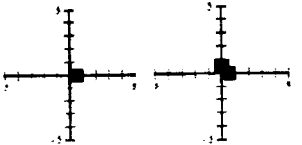
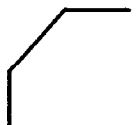
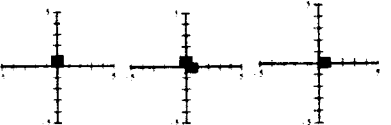
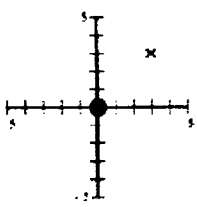
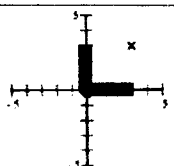
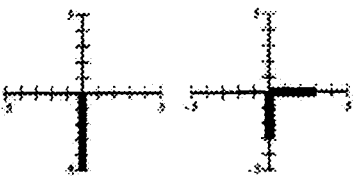
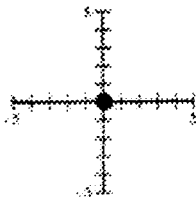
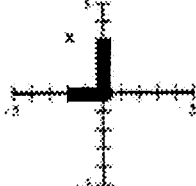

Answer	Count (%)	Sample explanation
Question 1. Show the impulse sequence above the paths. i) 		
ii) 		
Correct	26 (74)	
Incorrect	9 (26)	
Question 2. What path would a dot take if first you gave an impulse to the right (\Rightarrow), then an impulse upward (\Uparrow), and then an impulse downward (\Downarrow)?		
Correct	31 (89)	 
Incorrect (Incomplete answer)	4 (11)	Note: Students drew the correct paths only.
Question 3. What path would the dot take if first you gave an impulse upward (\Uparrow), then an impulse to the right (\Rightarrow), and then an impulse downward (\Downarrow)?		
Correct	31 (89)	 
Incorrect (Incomplete answer)	4 (11)	Note: Students drew the correct paths only.
Question 4. Given the target and empty data cross shown [below], fill in the stored impulses you would need to hit the target.		
		
Correct	35 (100)	
Incorrect	0 (0)	

Table 19 (Continued)

Answer	Count (%)	Sample explanation
Question 5. Which dot is going faster, the one on the left or the one on the right? Explain your reasoning.		
		
Correct	11 (31)	The one on the left because it all the impulse in one direction down on the dot.
Incorrect	24 (69)	<p>The one on the right because it has more impulses.</p> <p>-----</p> <p>The left because the right one would have a 3 speed and the left has a 6.</p>
Question 6. If you gave three impulses up and two impulses left, draw what the data cross would look like when you release the dot. Then, draw a target that the dot will hit.		
		
Correct	28 (80)	
Incorrect	7 (20)	

directions, showing that most of the students understood the concept of combination of impulses from different directions.

Question 5 showed two data crosses, one with impulses of -5 stored; the other with impulses of 3 to the right and 3 downwards. This question challenged students' understanding about the combination of impulses by asking them to predict and explain which dot was going faster. Most of the students (24) answered that the data cross on the

different directions to compare the resulting impulse. Therefore, they thought that the dot on the right would move faster. The students not only lacked the concept of the effect of combinations of impulses, but also lacked the knowledge of how to calculate the resulting impulse. In this case, the lack of mathematical skills seemed to affect student on their answers more than their understanding of combination of impulses.

Mass and the effects of an impulse: What is the relationship? (Homework 5,

Homework.pdf in the accompanying CD-ROM, see Appendix E)

Student answers (Table 20). The goal of this homework was to investigate how the mass of an object affects what an impulse does to its motion. The instructions (see Introduction Printouts.pdf in the accompanying CD-ROM, Appendix E) guided students to add dot prints, data crosses, timers, and a data table to help them to see what happened to a dot when an impulse was applied to the dot. Students used this homework as their guide for their in-class activities. They used the computer modules to gather the data for the homework questions and reach their conclusions. In the previous modules, students explored only the relationship between impulse and velocity in either one or two dimensions. Therefore, this homework (activity) required students to relate their understanding of velocity to exploring the relationship between mass and impulse.

There were two parts to this homework. The first part of the homework assignment asked students to examine the relationship between mass and number of impulses applied in a frictionless environment. Students set up two dots with different masses and gave the dots the same impulses to move the dot and then measured the velocities of the dots. Despite the fact that the environment was frictionless, we found that 11 (31%) students made their

hypotheses based on motion in an environment with friction. Two of the 11 students stated that the more mass an object has the faster the object will stop (Table 20). The rest of the 11 students hypothesized that the more mass the dot has, the shorter distance it will travel. This interpretation shows that about one third of the students based their hypotheses on their real life experience. These students had never experienced frictionless environment

Table 20 Mass and the effects of an impulse: What is the relationship? (n=35)

Part 1 mass and impulse		
Research questions	<ul style="list-style-type: none">How does the mass of an object affect what an impulse does to its motion?What will happen when a small ball and big ball get same size of impulse?	
	Count (%)	Sample answer
Hypothesis	16 (46)	If the mass of an object is greater, then it will need more impulse to reach the goal, because it's harder to push.
	11 (31)	If the mass is increases, then the impulse implied will make the object go slower because the object's mass has more friction.
	8 (23)	Note: the rest of the student answers have less commonality. Therefore, they are not listed here.
Conclusion	Yes, it supports my hypothesis because the force needed to move the object for a same distance would be greater than the force needed to move the heavier object.	
Laws discovered	<ul style="list-style-type: none">The higher the mass the lower the velocity assuming the force is the same.Jordan's law states that the more mass an object has, the slower it will move and the faster it stops.	
Real life examples	<ul style="list-style-type: none">1. A truck needs more energy to get as fast as a normal car. 2. When you throw a heavier ball, it will go slower.When you push a 10 lb. bowling ball and a 1 lb. marble, the marble will move faster.	
Part 2 Mass and friction (Students needed to state their laws only.)		
	Count (%)	Sample answer
<u>Sliding friction</u>		<ul style="list-style-type: none">
Law discovered	30 (86)	<ul style="list-style-type: none">The more mass there is the larger the affect that friction has on the object. The greater the mass, the larger the effect friction has upon the object.
	2 (6) (2 members in the same group)	<ul style="list-style-type: none">The mass by itself doesn't affect the friction, but since mass effect the velocity then it slows down faster, because it's slower and has less velocity to loose.
	3 (8)	<ul style="list-style-type: none">That the higher the friction you have, the slower the object moves. And the lower you have, the farther the object moves. (Not clear statements of the mass/sliding friction relationship.)
<u>Gas/fluid friction</u>		
Law discovered	28 (80)	<ul style="list-style-type: none">It's almost the opposite of what sliding friction does the one with less mass slows down and stops first and the one with more mass keeps going because it has more force against the air resistance. With fluid friction the higher the mass the longer it will stay.
	7 (20)	<ul style="list-style-type: none">Fluid/gas has far less friction than sliding friction.Gas/fluid friction causes an object's velocity to slow down. (Not clear statements of the mass/(air/fluid) friction relationship.)

in their everyday experiences. They utilized their prior knowledge, based on their experience, to make a prediction.

When students finished their experiment, all of the students concluded that their results did support their hypotheses because the dot that had more mass moved more slowly than the dot with less mass. In this activity, students were guided by the instructions to set up the dots to hit a wall/target to stop the dot, in order to measure the distance of the dot prints left behind. Students might have still believed that the dots would eventually stop in the frictionless environment because the dots, which were supposed to keep moving in constant velocities, were stopped by the wall. It is possible that due to the same reason as above, these students believed that their hypotheses were consistent with their results.

In part 2, students were asked to modify the Module 2 program (Investigating Friction using the Computer Model) to investigate how mass affects sliding friction and gas/fluid friction. They did the same setup as in the first part of this homework; however, different types of friction (sliding and air/fluid) were added to their experiment in this part. The teacher also modified the Module 2 package by adding some questions. These questions sought to guide students to explore the difference between sliding and air/fluid frictions. Students needed to state their question, write their hypothesis(es), record a sketch of their computer model, and describe how they would use the model to carry out their experiment. After they obtained their results, they needed to summarize their conclusions, state the laws that they discovered, and indicate how what they learned could be useful in real life. Almost all of the students (83%) understood that if an object with greater mass and an object with less mass were given equal impulses, the object with greater mass would travel less distance. Interestingly, one group of two students concluded that the mass of an object does not affect

the friction and that therefore it was the mass that affected the motion of the dots. These two students had set up a wall or a target to stop the dots before they were stopped by the effect of friction. Thus, the experiment they designed for part 2 may have produced results that were so similar to what they observed in part 1 so as to make it difficult for them to distinguish between the results of the experiments for each part. The similarities between the results in part 1 and part 2 might have led them to the conclusion they reached.

When students changed the sliding friction to air/fluid friction in the second part of the activity, 28 students' conclusions matched the principles of the motion under air/fluid friction. Although the rest of the students did not provide a clear statement of the mass/fluid friction relationship, their statements did not include an alternative conception. This computer experiment seemed to help most of the students realize the relationship between mass and air/fluid friction.

Posttest

Only the items that tested the same concepts as did the pretest were selected in order to compare student performance.

Understanding velocity (see Posttest Questions.pdf in the accompanying CD-ROM,

Appendix E, Item 4, Item 7)

Student answers (Table 21). Both items were multiple-choice questions. Item 4 asked students to choose the necessary elements to calculate velocity. About one third (11) of the students chose "c. distance and time of the motion" as their answer. This answer choice shows that these students were not able to distinguish velocity from speed. It is possible that students understood the difference between velocity and speed. However, when asked to

calculate the value of velocity, it was easy for them to ignore the direction of speed when direction was expressed in positive or negative symbols.

Item 7 required students to choose the factor(s) that changed the velocity of an object. Twenty-seven students chose answer “c. either its speed or its direction changes” in this item showing that they realized that velocity is determined by both its magnitude and direction. If we add the students who chose answer “b. its direction changes,” there were 32 (91%) students who realized that direction is a factor that changes the velocity of an object.

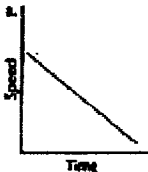

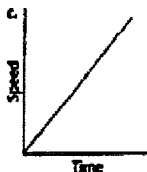

Table 21. Understanding velocity (n=35)
(The correct answer is indicated with a “*” sign.)

Choices	Count (%)
To calculate velocity, you need to know the total	
a. distance of the motion.	0 (0)
b. time of motion.	0 (0)
c. distance and time of the motion.	11 (31)
*d. distance, time, and direction of the motion.	24 (69)
The velocity of an object changes if	
a. its speed changes.	3 (9)
b. its direction changes.	5 (14)
*c. either its speed or its direction changes.	27 (77)
d. neither its speed nor its direction changes	0 (0)

Understanding the motion of an object represented in graphs (see Posttest Questions.pdf in the accompanying CD-ROM, Appendix E, Item 23-26)

Student answers (Table 22). Four items on the posttest asked students to select graphs that represented a car in motion with positive acceleration, standing still, negative acceleration, and a constant speed. The results show that more than 85% of the students realized the relationship between distance and time and the relationship between speed and time. Although Questions 8 and 9 of Homework 3 tested students on the graph concept, no

Table 22 Understanding the motion of an object represented in graphs. (n=35)
(The correct answer is indicated with a “*” sign.)

Use the graphs below to answer questions			
			
Answer	Count (%)	Answer	Count (%)
Which graph represents a car with positive acceleration?		Which graph represents a car standing still?	
a	0 (0%)	a	0 (0%)
b	0 (0%)	*b	35 (100%)
*c	30 (86%)	c	0 (0%)
d	5 (14%)	d	0 (0%)
Which graph represents a car with negative acceleration?		Which graph represents a car moving at a constant speed?	
*a	35 (100%)	a	0 (0%)
b	0 (0%)	b	0 (0%)
c	0 (0%)	c	4 (11%)
d	0 (0%)	*d	31 (89%)

pretest items tested students on this concept, which made measuring students' performance on this concept difficult.

Understanding Newton's laws of motion (see Posttest Questions.pdf in the accompanying CD-ROM, Appendix E, Items 12, 27-30)

Student answers (Table 23). Item 12 was a multiple-choice question. It required students to select the statement of Newton's first law of motion. Twenty-five (71%) students selected the correct answer. However, there were nine (26%) students who chose "A" as their answer. None chose "B" as their answer. This result suggests that it was easier for students to relate their real world experiences to Newton's laws of motion, because answer "A" (an object at rest will remain at rest) is a more common scenario in their real life experiences than an object moving in constant velocity. Implicitly teaching Newton's laws of motion in

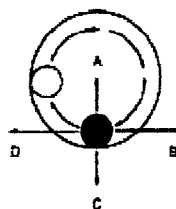
ThinkerTools activities might not provide enough clues for students to comprehend those laws and answer this kind of question correctly.

Items 27-30 asked students questions about the motion of two balls moving at a constant speed in a circular track. There were two parts to this question. The first part of this question asked students to explain whether the balls were accelerating. Twenty-nine students provided reasonable explanations, showing that 83% of them realized that direction is one of the elements that defines velocity. Nine students remained confused by the definitions of speed and velocity.

Table 23. Understanding Newton's laws of motion (n=35)
(The correct answer is indicated with a "*" sign.)

Item 12. The first law of motion states		
Answers		Count (%)
a. that an object at rest will remain at rest.		9 (26)
b. that an object in motion will remain in motion at constant velocity.		0 (0)
c. that an unbalanced force can change the velocity of an object.		1 (3)
*d. all of the above.		25 (71)

Item 27-28. Are the balls accelerating? Explain.



	Count (%)	Sample explanation
Correct	29 (83)	Yes, both balls are accelerating. This is because they are changing their direction of motion.
Incorrect	6 (17)	No because it said that they are going at a constant speed so it isn't.

Item 29-30. Predict which path the black ball would take if the wall of the track were to suddenly disappear. Explain.

	Count (%)	Sample explanation
Correct	32 (91)	D, because once there is nothing keeping the marble in the circle, there is no longer any centripetal force on it.
Incorrect	3 (9)	The black ball would go north because I am assuming that it has already begun to rebound in that direction.

The second part of these questions required students to predict the path and explain what would happen to the ball when the walls of the track were to suddenly disappear. Thirty-two (91%) students chose the correct answer and explained reasonably. When compared to Question 9 in the pretest, there were 19 (54%) more students who answered correctly. Although the data seemed to show students' improvement, there were no ThinkerTools modules helping students experience this concept. In addition, Question 9 in the pretest asked students to pick one possible path when the ball moves out of the "c" shape tube. In this question, students were tested on their understanding of the definition of acceleration and force that change the direction of the ball. These two questions may not seem to be equivalent. Student understanding might be possibly due to students' hands-on experiences during days 6-10, when in the class activity, the students rolled a marble around an aluminum plate that had a pie piece cut out and they tracked which way the marble went.

Understanding the model of force and motion (Item 35, Item 36)

Student answers (Table 24). Two items tested students on their understanding of the models of force and motion. Item 35 tested students' understanding about motion represented by dot prints. Students needed to draw patterns of dot prints to represent a dot that was speeding up and slowing down and then write down their explanations. Thirty-two (91%) students explained this question reasonably. When compared to student answers in Item 1 (15, 43%), Item 10 (16, 46%), and Item 11 (7, 20%) on the pretest, the number of students who answered the question correctly doubled. This change suggests that student understanding of motion represented by dot prints was improved.

Posttest Item 36 is the same question as Pretest Item 13. This question asked students to predict the motion of two dots, starting at the same height, which were then given different

impulses to the right and released simultaneously. Students needed to predict and explain which dot would hit the floor first. In Pretest Item 13 of the pretest questions, only six (17%) students realized the separate effects of impulses from different directions on the motion of an object. However, the result in Posttest Item 36 shows that the total number of students that answered and explained correctly was again doubled. This finding indicates that students gained further understanding on the dot print concept after ThinkerTools activities.

Table 24. Understanding the model of force and motion (n=35)
(The correct answer is indicated with a “*” sign.)

Answer	Count (%)	Sample explanation
Item 35. Make dot prints to show a dot speeding up and slowing down.		
Explain why you drew it this way.		
Correct	32 (91)	I drew it this way because dots closer together indicate slower movement and dots farther apart indicate faster.
Incorrect	3 (9)	Because if the dot prints are closer together they are moving fast and if they are farther apart, they are speeding up.
Item 36. Horizontal motion with gravity		
a	9 (26)	a, because it would only have to move 1 to the right and then fall to the ground, while the other one must move 3.
b	0	
*c	26 (74)	c, gravity would take effect on both of them right away, so then they would both hit the ground at the same time.

The answers and explanations for pretest, homework, and posttest questions were analyzed to realize students' understanding of the principles of Newton's laws of motion. This study also tried to understand students' attitudinal reactions to ThinkerTools package and how they used ThinkerTools to learn physics principles. Therefore, the answers for open-ended questions and the frequencies for the questionnaire items were collected and analyzed in order to understand students' attitudes toward ThinkerTools. Student interactions were also investigated in order to realize how students used the ThinkerTools program to learn the principles of motion and how ThinkerTools helped students learn Newton's laws of motion.

Open-ended questions

1. *What did you feel was the most important thing that you learned from using ThinkerTools?*

Most of the students stated that they learned about the relationships between motion and velocity/speed, friction and mass, impulse and mass, and Newton's law. However, one student described the situation she encountered as below:

"From using ThinkerTools, the most important thing that I learned was that the ball does not behave the way that a person would normally expect it to behave. This helped me learn a lot of concepts."

Two more students described their experiences of using ThinkerTools in terms such as, *"If you push something it doesn't want to stop,"* or *"You can never be too sure about what you assured."* These examples suggested that ThinkerTools did challenge students' prior experiences regarding the motion of an object and that the conflict helped students build their scientific conceptions about motion.

2. *What were you expecting to learn from ThinkerTools?*

Eight students had no idea about what they were about to learn using ThinkerTools. Two students were expecting to play games using the computer. The remaining students were expecting to learn concepts about motion, velocity, friction, and Newton's laws.

3. *What are the best features of ThinkerTools?*

Student answers (Table 25) showed that 17 (49%) students liked the features that allowed them to change the attributes of the dots, simulate the environment, and design their own experiment. Students seemed to appreciate using ThinkerTools to take control of the pace of their own learning. Seven students (20%) felt that ThinkerTools was easy to use;

Table 25. What are the best features of ThinkerTools? (n=35).

Category	Count (%)	Sample answers
Design experiment and change attributes	17 (49)	To change different things in the program, and then simulate them. I like that you got to control everything. How you can change attributes of the dot.
Easy to use	7 (20)	Its interface and simplicity How easy it is to use.
Like a game	4 (11)	That it is like a game so it is fun. Playing the activities
Miscellaneous	7 (20)	How real it is. It shows you picture.

meanwhile, four students (11%) enjoyed “playing” with ThinkerTools because they saw the program as a game. In the rest of the student answers, we found that one student liked the graphical interface of the program, and another felt the activities were close to reality.

4. *What are the worst features of ThinkerTools?*

Seven students (20%) did not think there were any worse features of ThinkerTools. There were a variety of different categories of student answers for this question. Four students did not like having to do a lot of setting up to make their own experiments. When compared to the four (11%) students’ answers in Question 3, we found that one of the students actually liked the activity of designing her own experiment. Four (11%) students complained that the introduction was not clear enough for them to understand. The unclear introductions could possibly explain the reason why the four students were frustrated by setting up activities. The unstable integration between the program and the laptop computer also frustrated four students. Two of the four students complained about the non-stopping timer while the others complained about the unreasonable number of times the program hung up. Interestingly, three students felt that the talking voice that showed up right after each task was quite annoying.

Two students complained about the control of the program. One of them was frustrated by the delay of the keyboard when she was trying to increase/balance impulses for the dot, while the other found it hard to use the touch pad of the laptop to measure the distance between two dot prints in Module 3 activities (Homework 4, Homework.pdf in the accompanying CD-ROM, see Appendix E).

Two students were confused when the dot was moving off the screen. These kinds of complaints were commonly found when we examined the in-class observation field notes, but it seemed that few students complained in their open-ended Questions. It is possible that students were getting used to it and paying more attention to their tasks after they used the program a number of times.

5. *Are there any parts of the area of motion that you believe you have difficulty with?*

Please tell me about these areas.

Only five students responded to this Question. One of the five students had difficulty understanding how the diagonal impulses worked. In Homework 3 (Homework 3, Question 5, Homework.pdf in the accompanying CD-ROM, see Appendix E), we found that only 11 (31%) of the students understood how diagonal impulses work. Class discussion right after each homework might have provided students the chance to understand the concept. Three of the students found velocity confusing. Two students were upset by the equation and the calculation for velocity.

6. *Can you explain how ThinkerTools helped and/or hurt you in trying to gain an understanding of the principles of motion?*

All of the students responded to this Question positively (Table 26). Fourteen (40%) students stated that ThinkerTools helped them visualize the actual situations that they were

not able to experience. Meanwhile, six (17%) students thought that the simulations in ThinkerTools were realistic, helped them relate the simulations to everyday life, and therefore helped them learn. Seven (20%) students responded that ThinkerTools aided them by allowing them to use the simulated environment to change the factors that affected the motion of an object. Students could therefore experience simulated situations that were not possible for them to encounter in their everyday life. One student's answer, "*It corrected my thinking on velocity,*" again shows that ThinkerTools conflicted with the student's prior experience and helped him build new concepts regarding the motion of an object.

Table 26. How ThinkerTools helped and/or hurt you in trying to gain an understanding of the principles of motion? (n=35)

Category	Count	Sample answers
Visual results	14 (40)	It showed visually through the trace dots how the distance, time, velocity, and all related in motion It helped so I could actually see it happening.
Realistic situations	6 (17)	Better understanding of Newton's law and showed a real life example. It helped us put experiments in real life situations
Hands-on experiences	7 (20)	It helped me understand better, because I could actually change the gravity and friction and all the other factors to see how they affect the ball's motion. We can experiment something that you are not understand.
Miscellaneous	11 (31)	It corrected my thinking on velocity.

Notes: 9 student not explained how ThinkerTools help them understand the principles of motion. Some students' answers were categorized in more than one categories; therefore, the total number of students counted exceeds 35.

7. What sorts of information did the data cross in ThinkerTools give you?

Twenty-three (66%) students realized that the data cross provided information about velocity and speed. Among these 23 students, only 5 of them listed both velocity/speed and direction, and only 1 of these students related data cross to impulse. As a result, two (6%) students referred direction only to data cross and seven (20%) students referred impulse only to data cross. One student stated, "*How far the dot would go and how fast it would go to,*"

showing that the students misinterpreted the information given by the data cross. However, the number of positive responses could be considered to be 32 (91%), because impulse and direction were both the kinds of information that a data cross could give while students were using ThinkerTools.

In-class observations

For the most part, students worked in pairs during the in-class activities. Two pairs of students were audio taped while working on the program. One of these pairs was closely observed by the author and field notes were taken. The audiotapes were transcribed by the author. The transcriptions and field notes were analyzed to identify patterns of interactions between the members of each pair and among students with the program. Students' interactions could be categorized into two major categories, the program issue and the physics issue. Under each of the major categories, interactions were classified into six subcategories: comment/complaint on program issues, cognitive conflict on physics issues, understanding of physics concepts, confusion about the program, mutual guidance on operation of the program, and misconceptions revealed. The sample interactions of different patterns of all target students were counted and listed in tables of each subcategory. Tables of total interactions of different patterns of all target students are presented in file: Student Interactions.pdf in the accompanying CD-ROM, see Appendix E.

Comment/complaint on program issues

This category covers the comments by individual students, interactions between the members of the pair, or interactions between the students and the program that focused on program issues. The stability of the program and students' ability to control and navigate the

program are also included in this category. This category also includes student conversations about the use of the program and their opinions about the pros and cons of hardware and software that were coded as their comments/complaint on ThinkerTools.

Because the program was not perfectly compatible with the hardware system, the program froze occasionally without reason. The compatibility issue also caused problems such as the timer not stopping when the dot hit the target, and the second set of keys to control the dot not working when students set up the second dot. Some students complained that the pointing device of the computer (the touch pad) was hard to control, especially when they needed to measure the distance between every two dot prints (Table 27).

Table 27. Comments/complaints on physics issues.

Issue	Interaction Counts	Example
Froze without a reason	5	Student 1: I see... Where is the target? Oh. I got it. Student 2: It froze once again.
Unable to set the second set of keys to control the dot	7	Oh, it's like ...something else because you screwed it up. I want to go up and down. Ours isn't going up and down.
Complaints on the touch pad of the computer	3	Student 2: Yes. Our mouse is too hard to control.
The timer did not stop when the dot stopped moving	4	Student 1: well, it didn't like say what to do. And so we just have it and it's not doing anything plus the timer's not stopping so we have to like pause it.

Cognitive conflict on physics issues

The conflict category includes instances in which the students' pre-existing beliefs/knowledge and the outcomes of their computer activities conflicted. A dialogue or interaction was classified as an example of cognitive conflict about physics if it:

1. Showed students dissatisfied with the computer outcome. For example:

I don't know what you're doing wrong, but look at that. Go back to the beginning of the maze... Make it go diagonal. Look, it speeds up.

2. Opened up an issue in a confronting manner. For example:

Student 1: Imagine a ball on a frictionless surface...two people hit the ball at the same time. They both hit the ball...at right angles to each other.

Student 1: All right.

Student 2: Umm, wouldn't it go diagonal?

Student 1: Yeah, it would go like this.

Student 1: Would the ball go at the same speed as if only one person hit it or would it go slower? Wouldn't it go slower? Cause it's taking some force off the sides.

The interactions in this category demonstrate that students encountered the cognitive conflicts on the concepts of motion with impulse from different directions, the relationship between impulses and mass, and the relationship between mass and air/fluid friction.

Motion with impulses from different directions

In the Module 4.4 program, some students felt confused about impulses in different directions that were exerted on the dot (Table 28). Some of these students typically believed that the resulting impulse would be generated by simply adding/subtracting the impulses from the different angle directions. The computer outcome conflicted with the students' beliefs on vector addition of impulses in different directions. Some interactions showed that these students believed that the dot would move at the same speed with the impulse in one of the directions as it did when being exerted in the same magnitude with impulses from right angle directions. Contrarily, some students believed that the dot would move faster when there were impulses exerted on the dot from right angle directions because they believed that the resulting impulse would be the sum of the impulses in both directions. The computer outcome also conflicted with students' beliefs because the dot did move faster when impulses were exerted in right angle directions. Another subcategory of interactions shows that the momentum effect of the program conflicted with students' beliefs of the motion of an object.

Their interactions showed that they had difficulty turning the dot in a right angle direction because of the impact of the momentum.

The relationship between impulses and mass

In Module 3 (designing an experiment to test the mass/impulse relationship), three interactions showed that some students still related their daily experience to the frictionless context because they expected the dots to stop when they set the simulated environment to be frictionless.

The relationship between mass and air/fluid friction

More interactions demonstrated cognitive conflicts as a result of Module 3 activities. When students switched the friction type from sliding friction to air/fluid friction, the computer outcome showed that the dot with greater mass moved longer than the dot with less

Table 28. Cognitive conflicts of physics issues

Issue	Interaction counts	Example
Motion with impulse from different directions. (Module 4.2 Run in a maze, Module 4.4 Hit the target)	8	Student 1: Imagine a ball on a frictionless surface...two people hit the ball at the same time. The both hit the ball...at right angles to each other. ... would the ball go at the same speed as only one person hit it or would it go slower? Wouldn't it go slower? Cause it's taking some force off the sides. I don't know what you're doing wrong, but look at that. Go back to the beginning of the maze... Make it go diagonal. Look, it speeds up. Student 1: Do we have to stop on it? Oh, we have to stop on it...Ok, now let's try to go back in there. You don't know how to do like the right angle? Stop.
The relationship between impulses and mass. (Module 3, Mass/Force relationship)	3	Teacher: Do we have friction on this? Student 1: We decided to go with non-friction. It goes forever. Student 2: It keeps going. Student 1: Weird.
The relationship between mass and air/fluid friction. (Module 3, Mass/Force relationship)	14	Are we going up to seconds? Sliding friction has more friction? Actually it has less...gas friction has more. No it doesn't, because it keeps going.

mass did. This scenario showed the reverse outcome as in the simulations with sliding friction. The outcome in the air/fluid friction activity conflicted with students' prior knowledge regarding (sliding) friction.

Students were more familiar with motion with sliding friction, especially when they finished the experiment about sliding friction. When they subsequently examined air/fluid friction, their beliefs, based on sliding friction conflicted with the evidence provided by the simulation outcomes.

Misconceptions revealed

In this category, interactions were classified as misconceptions revealed when there were alternative conceptions demonstrated in the interaction among students and computer (Table 29). The interactions in this category were organized into three subcategories:

1. Misconceptions about dot print concept

The most common misconception, as found in students' pretest answers, was that students used the frequency of dot prints per unit distance to represent the speed of the dot. Thus, rather than indicating a slower dot, more dot prints per unit distance represented a faster dot.

2. Misconceptions about calculating the magnitude of the resulting impulse

Without knowledge of vector addition, some students simply added the magnitude of impulses in different directions as the resulting impulses of the dot.

3. Misconceptions about the relationship between mass and air/fluid friction.

Air/fluid friction requires more advanced knowledge to understand the concept because there are more variables, such as mass, surface area, and velocity that affect this type of friction. In our observations, most of the students simply accepted the result that

the more mass a dot has, the longer it kept moving. One student explained his finding that the dot with more mass had more momentum to keep moving. However, the dots were set up to receive the same number of impulses and be released at the same time. Momentum equals to the result of force multiple the time that the force exerts on the object (momentum=force*time). Because the dots received the same number of impulses before it was released, they received the same magnitude of force in the same duration. In such cases, the dots should have the same momentum.

Table 29. Misconceptions revealed

Issue	Interaction counts	Example
Misconceptions about dot print concept.	2	Student 1: What happens to the space between dot prints when you apply more impulse to the dots? Student 2: There is less space in between them. Student 1: less space in between dots. (Module 1.1-Module 1.6)
Misconceptions about calculating the magnitude of the resulting impulse.	2	Two that way...three that way...two down...three up... That's not what I meant to do. That looks like a five...yup...5. (Module 4.4)
Misconceptions about the relationship between mass and air/fluid friction	2	It's not stopping...it probably should have stopped. What did you find out about this one? It keeps going, because it has more momentum. (Module 3).

Understanding of physics concepts as revealed in the in-class observations

During the ThinkerTools activities, when students tried to reach an agreement, group members would express their understanding verbally. In categorizing the student interactions, I identified instances in which the students expressed a correct interpretation of physics concepts (Table 30). The interactions in this category were organized in the subcategories shown below.

1. *Understanding the velocity change dot pattern when the dot moved under friction*

In this subcategory, interactions demonstrated students' interpretation of the dot pattern when the velocity of the dot was decreasing. This type of interaction was commonly found in students' conversation when they were using the Module 2 program (Designing an Experiment to Test the Relationship between Mass and Sliding Friction).

2. *Understanding the relationship between mass and impulse force*

When students expressed their understanding of the relationship between mass and impulse, the interaction was classified as understanding the relationship between mass and impulse. These types of interactions were commonly found in Module 3 (Designing an Experiment to Test the Relationship between Mass and Impulse)

3. *Understanding the impact of momentum*

In Module 4.2, when students were trying to turn the dot around a corner, they understood the impact of momentum after a couple of trials. Their interactions regarding their experiences on the momentum were included in this category.

Table 30. Understanding physics concepts

Issue	Interaction counts	Example
Understanding the velocity change pattern when the dot moved under friction.	3	I think I know what the pattern was supposed to be...it's supposed to be...3.75, 2.75, 3.25, 2.75, 2.25, 1.75, 1.25, then .75, then the next one will be .25...
Understanding the relationship between mass and force.	23	The force will be greater that moved the ball the same distance because the mass is more. It requires more force.
Understanding the impact of momentum.	3	Because when you stop it, it can go any direction. When you give the same amount of impulses, the opposite way stops it. Well...how else are you supposed to? Then when it stops it can go anywhere.
Understanding the relationship between mass and the distance that objects needed to slow down under sliding friction.	9	Student 1: because of the distance... required to the move at the same distance. Because the more mass increases the friction so ...
Understanding velocity/impulse.	22	Student 1: You give it an impulse to move it, then an impulse that combines with the current velocity to...they go together and then, like, the average angle.

4. *Understanding the relationship between mass and the distance that objects needed to slow down under sliding friction*

This type of interaction was commonly found in the Module 2 activity (Designing an Experiment to Test the Relationship between Mass and Sliding Friction). When students discussed their interpretation in order to write down the conclusion of their findings, their interactions showed their understanding of the difference between the distances that two dots with different masses needed to stop under the effect of sliding friction. However, when objects were moving on the same surface, the sliding friction should have remained constant, which means that the objects with different masses were supposed to slow down at the same rate. No evidence shows any of the participants noticed such a relationship. Therefore, student understanding of the relationship between mass and sliding friction was not supported in this set of data. However, most of the students stated that the more the mass of the dot, the more sliding friction it would encounter. This type of interaction showed students' misinterpretations about sliding friction. They typically saw that the lighter dot moved farther than the heavier dot before they stopped without noticing that they stopped at the same rate (the heavier dot stopped faster in a shorter distance while the lighter dot stopped slower in a longer distance). The teacher did not provide any explanation on this concept, which would endanger student learning in helping them build misconceptions.

5. *Understanding the resultant direction of the dot when an impulse is applied to a moving dot*

In each activity, when students' interactions showed correct interpretations of velocity, these interactions were then organized in this category.

Mutual guidance about operation of the program

When students were working in groups, there were interactions that demonstrated the way they corrected each other about the operation of the program. This type of interaction was classified as mutual guidance about the operation of the program between group members.

1. Guidance on setting up the program

When interactions revealed student guidance about how to set up their experiment or module to accomplish the assigned task, these interactions were classified in this subcategory. These interactions were commonly found in Module 2 and Module 3 activities because students spent time setting up their own experiments in these modules.

2. Guidance about operating the dot's motion

In Modules 1.1-1.6 and Modules 4.1, 4.2, and 4.4, students experienced the motion of the dot in different situations. Interventions regarding their mutual guidance related to controlling the dot's motion were frequently found in these activities. Therefore, these interactions were categorized in this subcategory.

Table 31. Mutual guidance on operation of the program

Issue	Interaction counts	Example
Guidance about setting up the program	18	Student 1: click on the dots, click the dots Student 2: there Student 1: double click on the dots. And do show mass.
Guidance about operating the dot's motion.	34	Student 1: Is this singing? No! The speed is on slow, or increase. Stop on it! No! Unknown-How do you make it stop? Other unknown-You push "S" and...

Confusion about the program

There were times students were confused by the instructions, operation, setting up, and navigation of the program. When student interactions demonstrated their confusion on these issues, the interactions were classified as confusion about the program (Table 32).

1. Confused by the instructions issues

There were times students were lost while they were using ThinkerTools. The interactions showed that they were asking Questions about instructions. They were lost because they did not know which instruction that they needed to follow (the steps were listed on the instruction sheets). These were classified as confusion by the instructions issues.

2. Confusion about the navigation of the program.

Some students were not able to find the location of the options on the screen. They followed the instructions to set up their experiment but were not able to locate the options that were listed on the instructions. The interactions demonstrating these situations were categorized in this subcategory.

3. Confusion about how to operate/control the dot's motion.

When students were working on the modules that required them to move the dot and to experience the motion of the object, there were times when students were lost because they did not know how to change the direction of the dot or how to stop the dot on the target. The interactions showing their confusion about these issues were categorized as their confusion about how to operate/control the dot's motion.

Table 32. Confusion about the program

Issue	Interaction counts	Example
Confusion about instructions issues	40	<p>Student 2: Okay.</p> <p>Student 1: What are supposed to do, Teacher?</p> <p>Student 2: 3.2</p> <p>Teacher: Did you read the directions? Follow right along.</p> <p>We can do the same thing, but we have to change the friction.</p> <p>What do you change the friction to?</p> <p>I don't know...maybe we shouldn't change it because it's the same thing. Teacher, how can we change the friction...?</p>
Confusion about the navigation of the program	52	<p>Teacher-No, no, this is page one.</p> <p>Student 1: Oh.</p> <p>Teacher-Ok.</p> <p>Unknown-You guys should have just done this.</p> <p>Student 2: Go to Edit Mode.</p> <p>Student 1: Edit Mode?</p> <p>Teacher-Under Run.</p>
Confusion about how to operate/control the dot's motion	30	<p>It was going too fast to hit the X. Then what do you have to do to make the dot go down? Go like this...I think it goes like this...then it goes like that... I don't get this one, though. It looks really confusing.</p>

Results from the questionnaire

Table 33 presents the percentage of students selecting each response on the opinion Questionnaire. On Items 1 and 3, more than 85% of the participants reported they had no difficulty understanding the information presented on the screen while they were using ThinkerTools (Table 33). Also, response to Item 9 indicated that 68% of the participants reported that they felt that the interface of ThinkerTools was easy to use to navigate through the program. These results indicate that students believed the interface design of ThinkerTools was simple enough for the students to utilize it as a tool to explore scientific principles. From my in-class observation, the interface of the program did not seem to be confusing to students. Students could easily follow the instruction on the screen to accomplish their tasks.

Table 4.26. Percentage of students choosing each response on the Questionnaire (n=100)

	Very Untrue of Me	Untrue of Me	Neither Untrue or True of Me	True of Me	Very True of Me
1. I easily understood the instructions on the screen while I was trying each activity.	0%	1%	21%	43%	35%
2. I had no problem in using the keyboard to control the movement of the dots.	0%	2%	5%	41%	52%
3. The information on the screen was too complicated for me to understand.	48%	41%	8%	2%	1%
4. The data cross and the numbers on the screen were distracting to me while I was trying the activities.	62%	29%	8%	1%	0%
5. The dot prints helped me understand the magnitude of the velocity of the dot as well as changes in velocity.	1%	6%	14%	45%	34%
6. In using ThinkerTools, there were times I felt I didn't know what I was supposed to do.	15%	26%	20%	33%	6%
7. The data cross on the screen helped me understand the difference between velocity and speed.	3%	11%	25%	36%	25%
8. Using ThinkerTools challenged some of my previous ideas about how motion works.	4%	9%	25%	45%	17%
9. The software interface for ThinkerTools was easy to use to navigate through the program.	3%	7%	22%	37%	31%
10. I like using ThinkerTools.	0%	2%	14%	44%	40%
11. The scenarios that the software provided are similar to my daily observations of object's movement.	9%	12%	37%	37%	5%
12. There were times when using ThinkerTools that the dot did not behave the way I expected it to.	5%	11%	17%	48%	19%
13. The scenarios that ThinkerTools provided were reasonable to me.	0%	0%	17%	61%	22%
14. ThinkerTools helped me understand Newton's first law.	1%	6%	24%	42%	27%
15. I believe that using ThinkerTools helped me to understand more about the principles of motion.	0%	3%	17%	54%	26%
16. I would like to use the software again.	0%	6%	19%	37%	38%

The data cross and the dot print were two key components that provided critical information to help students observe and understand the motion of the dot. More than 90% of the students reported that they did not think that the data cross distracted them when they were using ThinkerTools, while 61% of the participants reported that the information delivered from data cross helped them understand the difference between velocity and speed. Seventy-nine percent of the participants reported that they could understand the meaning of the dot print patterns. From these findings, students believed they could utilize the data from

the data cross and the dot print to help them understand the dot's motion. Students' answers to the Questions in Homework 3; supported this interpretation that most of the students seemed to understand the meaning of the dot print and the data cross after experiencing the ThinkerTools simulations.

From my observations, I found that there were times students were confused that the dot did not react to the keystroke until 0.5 seconds after students hit the key to exert impulses to the dot. This problem did not seem to influence the students' responses to the Questionnaire. On the Questionnaire, 93% of students reported that they did not have a problem using the keyboard to control the dot.

On Item 6, 39% of the participants reported that they either agreed or strongly agreed that there were times that they did not know what they were supposed to do when using ThinkerTools. Only 41% of the students reported that they disagreed or strongly disagreed in this situation. This result shows that 59% of the participants more or less experienced confusion about what to do while using ThinkerTools. While the students' responses to Items 1 and 3 indicated that they believed the interface was user-friendly, they also reported confusion about what they were supposed to do. It is possible that the handout instructions did not clearly guide the participants through the whole set of activities. However, from my in-class observations, there were times that students did not pay enough attention to the printed directions that were handed out by the teacher. Some students ignored the instructions and felt lost. More questionnaire items about the instructions might be needed to gather students' responses for further understanding the effect of the instructions.

Items 8 and 12 show similar results; 65% of the participants reported their conflicts between the simulated scenarios and their prior knowledge of the motion of an object. When

compared to the results of Item 11 (the scenarios that the software provided are similar to my daily observations of object's movement), only 42% of the participants reported that they either agreed (37%) or strongly agreed (5%) with the Question. This result confirms the results in Items 8 and 12 that there were times that the simulations conflicted with students' beliefs in motion. However, students seemed convinced by the scenarios that were generated by ThinkerTools because 83% of the students reported that they felt that the scenarios were reasonable to them while no students disagreed or strongly disagreed with the Question. Compared to the result of Item 11, the simulations made sense to most of the students even though some simulations conflicted with their prior knowledge of motion. It is possible that, by the end of this study, students constructed their understanding of motion by adjusting their alternative conceptions from those conflicts. Therefore, they responded that the simulations were reasonable to them.

In general, students reported that they felt the program was helpful in learning principles of motion (Items 14 and 15). Most of the participants (84%) also reported that they liked using ThinkerTools in learning Newtonian mechanics; meanwhile, 75 (75%) students reported that they would like to use it again. These results suggest that ThinkerTools did attract the participants' attention when used in learning principles of motion. The results were confirmed my observations. Most of the students seemed to be interested in learning physics in the alternative way provided by ThinkerTools. Students were excited when the teacher announced that they were going to use the computer to learn the concepts of Newtonian motion.

Cases

This research tried to study students' interaction with ThinkerTools, and the changes in students understanding of motion as influenced by the unit. Moreover, students' attitudinal reactions to the software and how students used ThinkerTools needed in-depth investigations. In order to explore the above issues, we studied particular cases that required intensive inspections both of the test results and homework answers and of the conversations between students and their partners during their class activities. Their conversations reflected student interactions with the computer and with their partners, their attitudes toward the software, and the moment of changes in students' understanding. When we studied students' dialogues and in-class observations along with the pretest, homework, and posttest answers of particular cases, we sought to present a systematic progress of student changes in understanding and attitude toward ThinkerTools package.

Two cases (student A and student B) were chosen from the selected subset of students for intensive investigations. One of the reasons why these two students were chosen is that they both had more active interaction with their partners than the other students in the subset during our observation. Therefore, we would have more chances to discover the changes in their understanding and their reaction toward the program. From the students that were randomly selected for our observation, student A answered more of the pretest Questions correctly showing that, although he still held misconceptions on specific concepts, he held fewer alternative conceptions than the other students. We sought to find out how ThinkerTools drew his attention, how he reacted to the program, and whether he could benefit more from using ThinkerTools than the other students. Student B answered most of the pretest Questions incorrectly showing that she held more misconceptions than the other

randomly selected students. Her learning process was investigated in order to understand how ThinkerTools helped her change her alternative conceptions and what her attitudinal reaction was toward the package.

Pretest

Understanding the model of force and motion

Dot prints representing the motion of an object

Student A

From student A's correct answers and explanations for Item 1 (horizontal speeding up dot print set) and Item 11 (free falling dot print set), we found that student A realized that the distance between dot prints would increase when the dot was speeding up. In his answer for Item 10 (dot prints representing horizontal motion with friction), "*Because when you give the impulses, the dots will speed up,*" he explained why he chose the set of dot prints with increasing distances as his answer. His explanation showed his understanding of the dot print idea although he chose the wrong answer.

Student B

Student B answered Item 1 (horizontal speeding up dot print set), Item 10 (horizontal motion with friction dot print set) and Item 11 (free falling dot print set) incorrectly. She chose answer B, which showed dot prints with decreasing distances between every two dot prints as her answer to represent a dot that was speeding up. This result suggested that she used the frequency of the dot prints to measure the speed of the dot.

In Item 10, she chose C, which showed the wrong dot print set (distance between every two dot prints was increasing) to represent a dot that was given an impulse on a surface with friction. From her explanation, "*It is stopped, so the dots are closer then the dot slowly*

starts to move again,” she seemed to understand the meaning of this pattern (speeding up) of dot prints, even though this answer was not correct (the correct answer was “B. slowing down”). It seems that student B was uncertain about the meaning of the dot print presentation of motion.

Student B chose A, the dot print pattern that had the same distance between every two dot prints, to represent the motion of a free falling dot in Item 11. She believed that the speed of the dot would remain the same, *“Its speed couldn't change.”* It is possible that she mixed up the principles of gravitational acceleration and velocity for a free falling object, or that she doesn't realize that a falling object is speeding up.

Student B's answers and explanation for this Question set show that student B had difficulty not only in understanding the meaning of the dot print set but also in relating everyday experiences to the motion of an object. Student A's explanation to his answers showed that he seemed to understand more about the motion of an object than student B although he occasionally selected the wrong dot print set. The idea of dot prints was a totally new experience for the students; these cases showed that students had difficulty understanding the meaning of the dot print set even though they could relate their experience to explain the motion of an object.

Falling object with horizontal impulses

Student A

In Item 13 (two dots released at the same heights with different impulses exerted on them), student A had difficulty relating his experience to an object's gravitational motion with horizontal impulse; he ignored the effect of gravity at the beginning of the motion in

Item 13 and explained, *“Because it wouldn't have to go to the right as much, it would just go a little then go down.”*

The same answer student A gave for Item 13 could be found in his response for Question 5 of the pretest. A paragraph describing two balls that were hit off the edge of a table by different sizes of impulses, *“Because the ball that's hit hard will go out a little before it goes down but the one that's hit less hard will go more straight down,”* showed his misconceptions about this type of motion. However, he answered Question 3, which tests the same concept as in Question 5, correctly. Question 3 showed the trajectory of the motion of a dot that was kicked off a cliff. The trajectories showed in Question 3 are shown in Figure 1.

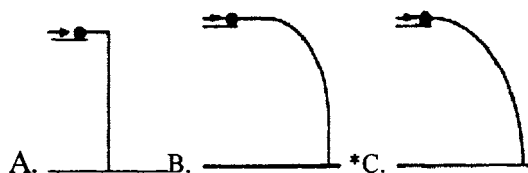


Figure 1. Trajectories shown for Question 3 (correct answer: C)

These graphics of the trajectories in Question 3 possibly helped student A visualize the motion and relate his experience to this type of motion.

Student B

Although student B answered Item 13 (Falling object with horizontal impulses) correctly, she did not explain the reason why she believed her choice was correct. Therefore, no detail of her understanding on this notion could be found.

Question 5 tested the similar concept (two balls were kicked off the edge of a table with different impulses) as Item 13. Student B answered Item 13 correctly but did not explain the reason. However, she did not choose the correct answer for Question 5, and her misconception on this concept was clearly stated in her explanation, *“With less force, the ball*

that wasn't hit as hard would drop right off the table at a right angle. The ball with more force would continue in an arc and then hit the ground taking more time to do so." In Question 3, she chose the wrong trajectory ("B") of a ball that was kicked off a cliff. Again, she could not relate the instant and constant impact of gravity to answer this question, *"The ball goes for a second because of the force behind it. Then it drops away in a curve to the ground because it is still gaining speed so can't go straight down."*

Question 3 showed the trajectories of falling objects for students. In student A's case, the visuals in this question (Question 3) seemed to help him relate his experience to answering the question. However, student B could not take advantage of the visuals in Question 3. It seemed that student B held a stronger alternative conception on this concept and she answered the question solely according to her misconception; therefore, the graphic did not affect her decision. However, because the teacher chose the modules to fit the time period and her instructional goals of this unit, no ThinkerTools modules regarding this concept were selected to help students in their learning in this unit. Student performance on this concept after using ThinkerTools therefore could not be investigated in this study.

Applying the model of force and motion

Motion with gravity

Student A

Students had no difficulty answering the sub items in Question 1 (two identical balls dropped from different heights). Like most of the students, student A had no difficulty understanding the straight down motion of a free falling object. Therefore, he answered and explained the subitems in this question correctly.

Student B

Student B held misconceptions on the motion of free falling. When asked to predict which of two identical balls that were released from different heights would hit the floor first (Question 1), she chose the higher ball as her answer. She believed that the higher ball would have more time to speed up and catch up with the lower ball, *“The higher one will speed up because it has more room to gather speed, then catch up with ball A.”* The constant acceleration, G , from gravity was ignored when she related her experience to the answer of the question. With the same belief, it is not surprising that she answered correctly when being asked about which ball would be going faster when it hit the floor.

This concept (free falling) did not seem to be difficult for most of the students. Student B was one of the six students who believed the higher ball would catch the lower ball because the higher ball had either more room or more gravity to speed up and catch up with the lower ball. Again, since no modules regarding motion under gravity were selected to be used in this unit, further study might be needed to test student performance after using ThinkerTools.

Understanding Newton's first law of motion

Student A

Student A answered Question 2 (predict the motion of a coasting spaceship) and Question 4 (drop a ball into a bucket while you are moving) correctly, thus showing his basic understanding of inertia. However, when being asked about the path of a ball that just moved out of a “C” shape tube (Question 9), he answered the question incorrectly and explained his answer using a misinterpretation similar to his explanation in items that were discussed earlier (Item 13 and Question 5), *“Because the ball will still move in a circular motion, so it*

wouldn't be C, but A makes it go too far in a circular motion so it has to be B" (correct answer: C).

In Item 13 and Question 5, student A related inertia to the horizontal motion of the dot without considering the simultaneous impact of gravity. In Question 9, student A noticed the effect of inertia but ignored the disappearance of the force that keep the dot moving in a circle. Student A also interpreted that inertia would keep the dot moving in a circular direction. However, student A did not choose answer A because he thought, "*A makes it go too far in a circular motion.*" It is possible that student A justified his answer with his everyday experiences.

Student B

Most of the students had no difficulty understanding the concept (inertia, first law) in Question 2 (predict the path of a coasting spaceship). So did student B. She stated, "*Space is a vacuum, and with nothing to pull the space ship in with its gravitational pull, like planet, star, and black hole, the spaceship has nothing to make it need to speed up or slow down by force or nature.*"

Question 4 (trying to drop a ball into a bucket while you were running) also tested students on the concept of inertia. Student B held an alternative conception of this concept. She believed that the ball would be pushed backward and therefore needed to be released at the point ahead of the bucket, "*The force against the ball would force the ball backwards, but not much, so one would want to drop the ball almost at the bucket but just a few inches past.*" Note that this is the visual pattern from the viewpoint of the runner. The ball seems to fall away backwards from you. However, she answered Question 9 (a ball shooting out of a "C"

shape tube) and explained correctly, *“The only thing keeping the ball from going straight in the first place is the tube, so since it doesn’t exit, it will continue at that straight path.”*

In Question 4, student A visualized the trajectory of the falling ball and predicted its trajectory correctly. Meanwhile, student B used herself as the frame of reference to predict the trajectory of the ball and therefore answered the question incorrectly. Both students interpreted the concept of inertia of linear motion correctly (Question 2). Students would experience the inertia in linear motion and their reaction is discussed in a later section. Student A’s explanation for Question 9 (the circular motion) was consistent with his interpretation on inertia because he believed that the dot would travel with a “circular” inertia a short time after it was shot out the “C” shape tube. Despite the wrong answers for most of the motion questions, student B answered and explained Question 9 correctly. It was possible that the graphical presentation of the path of the ball helped her relate her experience and visualize the path of the ball. It also showed that student B was carrying out local, situation-by-situation reasoning for those questions. Unfortunately, ThinkerTools package is not capable of generating a scenario such as in Question 9 to help students experience this pattern of motion. Further study and a more complete system might be needed to test student performance on this topic.

Understanding Newton’s second law of motion

Student A

In Question 14 (balls with different mass hit by the same amount of impulses), student A could not relate the factor “mass” to the motion of the balls. In his explanation for his answer “C, both balls will have the same speed,” he wrote, *“Because they were hit with the same force so they will stay at the same speed.”* However, ThinkerTools helped student A

relate the relationship between mass and impulse to the motion of the dot in a later module (Module 3, Design an Experiment to Test the Relation between Mass and Force). His performance is discussed in a later section of this case study. Question 15 demonstrated two identical pucks hit by equal impulse on two different surfaces (smooth and unsmooth). Student A answered this question correctly probably because the mass factor was removed from this question. Like most of the other students, he had no difficulty relating friction to the motion of an object. He wrote, *“Because the friction will slow the gray puck down,”* and *“Because as the friction increases, the speed will decrease.”*

Student B

Student B answered Question 14 (two balls with different masses that were hit by the same impulses) correctly and related her everyday experience to explaining her reasoning. She believed that the lighter ball would have a higher speed after the hit.

Question 15 demonstrated two identical pucks on two different surfaces (smooth and unsmooth) hit by identical impulses. Student B answered this question correctly, possibly because this kind of question was more close to her real life experience, *“The friction slows the puck down and it eventually stopped. The unsmooth surface would provide obstacles to hinder the distance traveled.”*

Both of the students answered and explained their answer for this question correctly. However, more than 80% of the students answered this question correctly. It seemed that students had less difficulty relating their everyday experience to motion under the effect of friction. The result is not surprising because students are surrounded by the effect of friction in their everyday lives.

Understanding Newton's third law of motion

Student A

In the series of items in Question 7 (a static black ball hit by a moving white ball from the left of the black ball), student A answered correctly only in the questions that asked him to answer if there were impulses exerted on the static and moving balls (7-1, 7-4). When asked to predict the direction of the impulse exerted on the static black ball, he chose “B, to the left (←)” as his answer. He believed that, *“The white ball exerts force because the person that hit the ball had force that carried on to the black ball. The force on the black ball is to the left because that's where it got hit from.”* His explanation for the direction and force on the white ball was similar to those of the other students, *“The black ball has pressure on the white, that's why the white ball stops. It has no force because the white ball stopped all of its force.”*

He believed that there was no force exerted on the moving white ball when the white ball hit the black ball because it stopped after it hit the black ball. Student A's explanations showed that he had difficulty realizing the spontaneous effect of the force (energy) transfer when the two balls hit each other. From students' answers for Item 4 of Question 7, more than one third (13) of the students believed that the black ball did not exert force on the white ball because the white ball became static after it hit the black ball, for example, *“The ball has no force because it was just sitting there.”* Frequently the students believed only the moving objects had impulse exerted on them.

Student B

Unlike student A, student B answered correctly only on the questions that asked her to predict if there was any force exerted on the moving ball (7-4, 7-5). She had difficulty

understanding the phenomenon because she believed that only the black (static) ball exerted force on the moving ball (the white ball) and it made the white ball stop, and then the black ball carried the force and started moving. Therefore, she answered that there was no force acting on the black ball when they hit, *“When the 2 balls hit, the white ball is forced back or stay still while the black ball continue on.”* It is obvious that she related her belief in Question 7-1 and Question 7-2 to predict the direction of the force that acted on the white ball in 7-4 and explained, *“When the 2 balls hit, the black ball exerts a force on the white ball, stopping it. This force propels the black ball forward.”*

It seems that students had total difficulty understanding the concept of forces resulting from interactions. Nevertheless, no modules were selected or designed for this unit to facilitate students learning this concept, which made the relationship between student performance on this concept and using the ThinkerTools package remain doubtful.

The impact of forces from different directions

Student A

In the questions that tested students' understanding of the effect of the combination of forces from different directions (Questions 8, 10, 12, and 13), student A answered correctly only on Question 13. Like most of the students, student A seemed to have had no real world experience to help him understand the combination of forces applied to a moving object. In Question 8 (compare the motion of boat A in a river with a flowing current to boat B in a river without current, both boats crossing rivers of the same width), he stated his interpretation as, *“Because the fastest way to get from one place to another is a straight line that's what boat B did.”*

This question showed students the graphics that boat A moved diagonally to the opposite shore while boat B moved straight. It is also possible that the graphics showing a longer path for boat A and a shorter straight path for boat B led to student A's conclusion.

In Question 10 (a rocket turned on a short burst while it was coasting along sideways in deep space), he possibly related his experience in gravitational motion and took the short burst as a constant force exerted on the spaceship. Therefore, he believed the spaceship would not go straight "down" but would go curvedly "down" like a ball that was kicked off a cliff, and chose answer C. The graphic for this answer is shown in Figure 2.

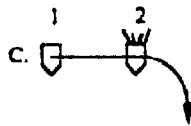


Figure 2. Graphic shown for Question 10.

He used "down" to describe the direction of the spaceship's motion. It is possible that the graphics of the question showing the spaceship moving toward the bottom of the page misled students to interpret the motion as gravitational motion from their everyday experience. Questions 12 and 13 tested students on the same concept (predict the direction of impulse needed to turn a moving object through a specific angle). The graphics in this question is shown in Figure 3.

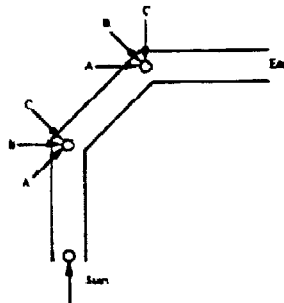


Figure 3. Graphic for Questions 12 and 13

Student A had difficulty relating the concept of momentum to this type of motion in Question 12; therefore, he wrote, “*Because A directs it the same way as the path.*” This kind of answer was common in students’ answers since they had little experience with momentum. Although student A chose the correct answer for Question 13, we were not able to know his interpretation for his answer because this question did not require students to write down their explanation.

Student B

In the questions that tested students’ understanding of the effect of the combination of forces from different directions (Questions 8, 10, 12, and 13), student B answered none in this category of questions correctly.

In Question 8 (compare the motion of boat A in a river with flowing current to the motion of boat B, which is in a river without current.), student B, like student A, used her mathematical knowledge to explain why she chose B as her answer, “*A straight line is the shortest distance possible.*” It seems that students were assuming the velocity of both boats was the same and therefore the object with the shorter path got there first. The lack of the knowledge of vector combination also could be one of the reasons that led them to reach such a conclusion.

Student B chose the same answer in Question 10 (a rocket turned on a short burst while it was coasting along sideways in deep space) as student A did. However, she showed the ideas of impulse and inertia in her explanation, “*The rocket will continue on its drift briefly, gain its speed, and go forward a short distance, though will continue drifting shortly after the short burst.*” She briefly showed the idea of inertia and the impact of impulse but

failed to select the correct graphic as her answer. It is possible that student B had difficulty translating her verbal understanding to visual presentation as the motion of the rocket.

In Question 12 and Question 13 (predict the direction of impulse needed to turn a moving object in specific angle), she predicted that the direction of the impulse needed for the ball to turn into a specific direction must be in the same direction as its ongoing path and chose the direction A, *“It would hit the other side right away by the other two.”*

Most students had difficulty answering questions that tested the concept of combination of impulses. Both student A and student B could not answer all the questions (Questions 8, 10, 12, and 13) that tested students on this concept correctly. ThinkerTools gave students the chance to experience and test their prediction on this concept. Student performance is discussed in the observation of their conversations with their partners during the activities using ThinkerTools modules. The result is presented in a later section.

Module 1 (The Effect of Impulses in a One Dimensional World)

Student A

In this activity, students experienced the one-dimensional motion of an object simulated by ThinkerTools. Student A was excited when he knew he was going to “play” with the computer program as a part of his physics class. In Module 1.1, Speeding Up, he first tapped the “F” key in order to get the highest velocity for the dot; however, after practicing a couple of times, he and his partner figured out that by holding the key down the dot could reach the highest speed easier. (Note: the function keys that controlled the motion of the dots are: “F”, one impulse to the right; “S”, one impulse to the left; “E”, one impulse upward, and “C”; one impulse downward.)

Student A: What is the highest velocity you were able to reach?

Partner: Describe what you did you when you reached your highest velocity.

Partner: Pressed the "F" key and held it down.

Student A: Held down instead of tapping fast.

Their reaction toward the operation of the program showed that they did not seem to realize the idea of the relationship between the number of impulses applied and speed in the first module. However, in the later modules, the program, homework, and instructions would guide students on how to utilize the impulses on the speed of the dot in order to accomplish the tasks. For example, the Homework 1 questions used footprints questions to help students relate their everyday experience to the idea of dot prints because footprints are more realistic to students' everyday experience of motion than dot prints. In Homework 1, students were given footprint patterns left by a person to show this person's motion. Like most of the students, student A had no problem answering these questions. Student A also answered the questions in the second part of Homework 1 correctly. The second part of Homework 1 asked students to measure the distance between the dot prints left behind a dot and to predict the dot's motion. Student A had no difficulty answering the question since he answered the dot print questions in the pretest correctly showing that he had more understanding on the dot print idea than most of the other students.

In Module 1.2, Stopping, students needed to stop the dot on the target. When they spent more time in this module, they developed their strategy to solve their problem.

Partner: Go to 3 and then press it. Keep going.

Student A: Oh yeah, because you got to hit backwards.

Partner: Yeah, and then you have to hit the button and it will get backwards one.

So, if you go to 3...

Partner: Now press stop.

Student A: Yes!

Partner: You did it.

From their conversation, we realized that they were able to use impulses of different directions to balance the velocity and hit the target at the required velocity. Compared to their reaction in Module 1.1, they pressed the key more cautiously in Module 1.2 to control the velocity of the dot. Their reaction showed that they were implicitly guided by the program to get the idea of the effect of impulses on velocity.

There were times that they would encounter tasks (Module 1.3, Different Velocities) that asked them to hit the target at negative velocities. They used the same strategy of balancing velocities to accomplish their tasks:

Partner: Now it's negative 3. Umm...

Student A: Oh wait you are going backwards.

Partner: No, we just hit it more times and then hit backwards more times.

The tasks assigned by the package helped them to develop their strategy to solve the problems and helped them understand the meaning of velocity in different directions.

Their understanding was revealed in their later conversation:

Student A: You got to keep going until you pass the whole thing (the target).

Student A: If the dot were moving at a velocity of 1 and you wanted to move at a velocity of negative 1, what impulse would you give it?

Partner: Negative 2.

Student A: Yeah.

Student A: Yes! What does a negative velocity mean? Going backwards.

Partner: Going in the left direction.

At the end of this activity, they realized the principles of velocity. Their understanding of the meaning of negative velocity was revealed in their conversation. They guided each other with their experience of accomplishing their tasks, and then they reached their agreement and gained understanding.

When they moved on to Module 1.6, Moving Dots, they encountered the problem that the dot moved upward automatically when they started the program,

Student A: Okay it's up off our screen. Whoa where is it going?

Partner: Whoa! I didn't even press a button. At a velocity of 3.

Student A: Stop!

Partner: It just starts it right away. Whoa, go back.

Student A: Where did it go?

ThinkerTools program was not integrated with all of the computers perfectly. Some of the laptops that we used in this study were found to be somewhat incompatible with ThinkerTools. The software was developed more than 10 years ago and it works better on older machines. It seems that the software was not compatible with the faster machines which caused the problem.

Student A then started to work on his homework questions. It was hard for students to relate their real world experience to motion with impulses in two dimensions. In their discussion for the predictive questions, when they encountered the question: "Imagine a ball on a frictionless surface, two people hit the ball at the same time, they both hit the ball at right angles to each other," their conversation showed their misconception and conflict:

Partner: Umm, wouldn't it go diagonal?

Student A: Yeah, it would go like this.

Student A: Would the ball go at the same speed if only one person hit it or would it go slower? Wouldn't it go slower? Cause it's taking some force off the sides.

Their discussion indicated that they had no idea about how to balance the impulses in the directions of right angle, although they could predict the final direction of the velocity of the dot. The same interpretation of the magnitude of the resulting impulse (velocity) was also found in student A's explanation for Question 5 of Homework 3. In this question, students were asked to predict which of two dots was going faster, one hit by 5 impulses downward,

or the other hit by 3 impulses downward and 3 impulses to the right. Student A explained for his answer, *“The right (3 impulses downward and 3 impulses to the right), because it has more impulses.”* He calculated the resulting impulse by simply adding the impulses in different directions. It is possible that the lack of the mathematical idea of vector combinations caused his misunderstanding.

Student B

Due to equipment problems, no conversation between student B and her partner was recorded. However, the in-class observations indicated she was interested in using the computer in learning physics. She was first confused by the delay of the keyboard reaction in Module 1.1, Speeding Up. When she was trying to give impulses to the dot by hitting the keys (“S”, “F”, “E”, and “C”); in this activity students usually only hit the “F” key because the target was on the right side of the dot), the effect of the acceleration showed on the dot about 0.5 second after she hit the key. After a couple of trials, she held the key down to accelerate the dot in order to hit the target like student A did in the same activity. In Module 1.2, Stopping, while her partner was still trying to hit the target, she noticed that they needed to stop on the target in this module. Also, they did not notice the timer that was recording the time they spent to hit/stop the target until the group next to them mentioned the timer. In addition, they did not pay attention to the instructions when they both concentrated on the program. At the end of this activity, her partner realized that the velocity on the data cross would be zero when the dot stopped on the target. At this point, the data cross drew their attention and it was possible that they started to realize that they could make use of the data cross to accomplish their tasks.

In Module 1.3, Different Velocities, and Module 1.4, No End Walls, student B and her partner were lost about how to reach negative velocities on the first trial, but they picked it up in a short time. In addition when they were trying to compare the time that the dot spent to hit the target, they found that the timer did not stop when the dot hit the target. The non-stopping timer confused them when they needed to gather information from the timer. In Module 1.3, the negative velocity that was required to hit the target confused them. They did not realize the relationship between the negative sign and the direction of the motion of the dot at the beginning of this module.

Like student A and his partner in the previous case, they also developed their strategy by passing the target and then moving the dot backward to hit the target with negative velocity. In Module 1.5, they developed their strategy to accomplish the tasks. When they needed more room for the dot to move backward and get negative velocity, they started to use the information on the data cross to predict the dot's direction and velocity. They found it useful especially when the dot was out of the screen. In Module 1.6, Moving Dots, there is no wall at the end of the vertical track. When they encountered the required velocity of -7 , they needed more room for the dot to accelerate from bottom of the track to the top of the track and then move backward to reach the velocity of -7 after it passed the target. Frequently their dot reached "the edge of the universe," which means the dot was too far out of the window of ThinkerTools when they were trying to accomplish this task. The computer program halts when the dot reaches the "end of the universe."

Student B answered all the questions in Homework 1 (Footprints) correctly. This result showed that she had no difficulty relating footprints that a person left behind to the speed/velocity of the person. In the second part of this question, she showed her

understanding of the dot print analysis of a ball's motion. Student B realized the speed and the direction from the printout showing the dot print pattern left behind a bonked dot, *"They both started out with one bonk, which made them both go at the same constant speed."* When being asked about a second bonk that hit the dot, she could relate the impulse that was exerted on the dot to the dot's motion, *"An amount of force was applied to an already existing force, doubling the speed."*

The modules used in this activity gave students the chance to visualize the dot prints left behind the dot at the same time the dot was moving, in order to experience the impact of motion in negative velocity, and to utilize the data cross to predict the dot's motion. The homework questions helped students to relate their everyday experience to the abstract physics concepts being taught. Also in this series of activities, we found that there were times that students were guiding each other to accomplish their task. Moreover, students corrected each other's ideas during their discussion before they reached their agreement. The program and the assigned tasks facilitated collaborative learning and students achieved their understanding on physics principles without explicit instructions.

Module 4 (The Effects of Impulses in Two Dimensions, 4.1, 4.2. Motion in a Maze, 4.4. Hit the Target), Module 2 (Modeling the Effect of Sliding Friction)

Student A

In Module 4.1 (move the dot in a right angle track to hit the target), student A failed to stop on the target on the first couple of trials. Then he figured out the pattern which could go around the corner:

Partner: Can you make a dot go through the questions...how do you make a dot do a right angle turn?

*Student A: You slow down then you stop...
...Slow down then stop...*

Student A: Because when you stop it, it can go any direction. When you give the same amount of impulses, the opposite way stops it. Then when it stops it can go anywhere.

At the end of this module, he developed his strategy of stopping the dot by providing opposite impulses to balance the momentum of the dot, so that the dot could then go in different directions. When he went through the modules, he understood the combination of impulses in different directions.

*Student A: In general, what do you do to make the dot go diagonally?
Partner: You have two impulses that are in the direction that you want it to go.
Student A: So make it have two impulses?
Partner: Yes...sometimes.
Student A: Why do you think this works? Because the impulse from both ways in equal...equal impulses from each ways goes up the middle...*

The computer simulation provided student A the chance to experience the effect of momentum. This module also guided student A to explore the effect of impulses from different directions on a moving object. Students took advantage of the program that they could try the simulation as many times as they wish. In doing this, they reached agreement on their understanding of momentum and the impact of impulses from different directions.

In Module 4.4, the data cross also helped student A visualize the impulses stored in the dot and the direction of the dot's motion before student A hit the space bar to release the dot. He counted the impulses that presented as bars in different directions on the data cross.

*Student A: That's 6 and 2 or 3 and 1...one more...
Partner: You actually got the fast one to do. Cool.*

From their conversation, I found that student A realized that impulses of 6 and 2 from 90 degree directions moved the dot in the same direction as impulses 3 and 1 from 90 degree

directions did. They also figured out that the resulting impulse from impulses of 6 and 2 actually would make the dot move faster. Their interaction showed that they were able to make use of the information on the data cross to predict the impact of the resulting impulse.

In Homework 3, there were two questions (Questions 2 and 3) that asked students to draw the path and the impulses of a dot according a description of the impulses that were exerted on the dot. Moreover, two questions in this homework (Questions 4 and 6) asked students to draw on a data cross the impulses that were needed for a dot to hit either a given target or a target that students were required to predict and draw the position of. These questions generated the scenarios that were similar to the scenarios in Modules 4.1, 4.2, Motion in a Maze, and Modules 4.4, Hit the Target. Except for Question 5 of Homework 3, student A answered all the questions regarding the concept of data cross in both Homework 2 and 3 correctly. It seemed that these activities (Modules 4.1, 4.2, and 4.4) and the data cross helped student A use his experience from the activities to answer the questions in the homework. Question 5 in Homework 3 shows two data crosses with two sets of impulses stored in the dots, one with 5 impulses downward and the other with 3 impulses downward and 3 impulses to the right. As discussed earlier, students needed advanced knowledge (vector combination) to predict which dot would go faster.

During the activity using the Module 2 program, students spent more time on learning how to set up the properties of their simulated experiments than on testing the results. Because this activity was the first one that asked students to set up their own experiment, student A and his partner spent more than half of the time in class reading the instructions and trying to figure out how to set up their experiment. Even when they finished setting up their experiment, they were lost about how to begin:

Student A: What are we supposed to do after this? Do we have to do this?

Partner: Are we supposed to be recording any of this or do we just do it?

Student A: Make it all zig zaggy. Make a maze or something. Are you going to try two dots? Are we supposed to make another one?

Students were learning how to design their experiment in this activity in preparation for the next activity, in which they had to design their experiment to test their hypotheses. At the end of this activity, they were supposed to be able to measure the distance between dot prints in order to calculate the velocity or the change of velocity. Interestingly, when they realized how to set up the properties for the dot and the simulated environment, they were eager to try each different option and test the results. Therefore, by the end of this module activity, students were “playing” ThinkerTools. They designed their own environments by setting up different environment variables such as friction, the direction of gravity, the bouncy dot, and circle walls. For example, one group built a bowling game by placing 10 dots together and used another dot to hit the dots. When students were able to utilize the software as a tool for exploration, they seemed to be more actively engaged in the learning process.

Student B

Student B failed to get the dot to turn the corner of the maze in module 4.1 (Turn a Corner) because she did not have experience with momentum. After several attempts, she realized the effects of momentum and slowed down the dot at the corner before she changed the direction of the dot. After a couple of trials, she and her partner quit Module 4.1 and started practicing Module 4.2 (Run in a Maze). Her partner spent more time on Module 4.2; therefore, student B had less time to practice. At the beginning of the Module 4.2 activity, the diagonal path of the maze frustrated student B because it required one more turn to hit the

target. With the experience gained in Module 4.1, student B was more cautious than she was in Module 4.1 when she was turning the dot at each corner.

The problem of the recording machine was fixed on the day the students were doing Modules 4.1, 4.2, 4.4, and Module 2 activities; therefore, students' conversations were audio taped again. In Module 4.4, student B and her partner realized that the impulses of different directions could be stored in the dot and then they could release the dot by hitting the space bar:

Partner: This works because they could go backward. You can hit in two directions so... it would go backward.

Student B: It goes faster when... OK, it goes faster. It goes faster.

They accomplished the first task in this module by trying different combinations of impulses in different directions:

Partner: You need to hit the space bar.

Partner: I got like ... because this force...

Student B: Two right? OK...

Partner: Four, and three..., four and two..., four and one... (setting up the speed).

OK. One and three... here we go.

Student B: So it's like glue at wall.

Because they spent more time on Modules 4.1, 4.2, and 4.4, these students did not have much time to work on the Module 2 program. In the Module 2 program, switching between edit mode and run mode confused students again because there were times that the dot did not move when they hit the space bar and then they realized that they were actually in edit mode. The similar interfaces between "edit mode" and "run mode" confused students during the Module 2 activity. It would have been easier for students to realize which mode they were in if these two modes were separated into two different windows. It also took more time when they tried to figure out how to measure the distance between every two dot prints

left behind the dot. In this class period, student B and her partner seemed rushed to finish their activities, especially in the Module 2 program, because they needed to write down their results as their homework answers.

After practicing in these modules, student B answered most of the questions in Homework 2 and Homework 3 correctly. She could draw the correct directions and the magnitudes of velocities that were needed to turn the dot at the corner on the data cross according to each turning point of the dot's path in Question 1 and Question 2 of Homework 3. From her answers for Questions 3 and 4 in Homework 2 (predict which dot was moving faster from the dot print left behind), we could sense her understanding of the patterns of dot prints that were left behind a moving object, *"White, The dots are further apart, which means it traveled farther in one second than the black marble"*(Question 3); *"Black, The dots of the black marble are getting farther apart, with more distance between them, while the dots of the white marble are getting closer together"*(Question 4). Like most of the students, student B had difficulty understanding the magnitude of the resulting impulse that resulted from the combined impulses in different directions. In Question 5 of Homework 3, she simply added the impulses in different directions as the resulting impulse on a dot, *"The one on the right because it has six (3 down and 3 right) impulses build up."* But the vector addition, based on the Pythagorean theorem is pretty advanced for these students. Recognizing that the combination is greater than each singly is a conceptual advance.

Student B had the whole class period for Module 2 (Design Mode). When she and her partner were setting up their experiment, they had the common experience of feeling lost in setting up a target for the dot to hit:

Partner: Is there a target to hit or something?

Teacher: You have to put the target in, if you want a target.

Partner: Where is the target?

Partner: Where are we now?

Partner: You don't have a target do you? Where did you get it from?

Group member in the group next to them: You just click on that little cross thing.

Partner: Oh.

From the in-class observation, it was common that students put a target in to stop the dot.

Students read the instructions to set up their experiment, however, to set up a target to stop the dot was not mentioned in the instructions. The instructions guided students to choose "Pause" on the "Run" menu to pause the dot and then use the ruler to measure the distance between every two dot prints. It seems that the experiences from the activities in Module 1 told students that the dot would stop only when it hit the target, because in Module 1 the dot could only hit or be caught by the target to stop. Students' understanding of motion with friction became doubtful because, since the dot's motion was paused by students before it stopped by friction, students did not notice that the dot would eventually stop.

After they finished setting up all the property and getting their data, they started to play with the program. They changed the property of the dot to bouncy and hit the dot with the other bouncy dot.

Partner: Yes! See.

Student B: That's nice.

Partner: Watch this, do it again. Hey, want to see something neat? Want to see something neat? Watch this. Watch this. Ready, do you see it?

Members of the group next to them: Nice. How did you guys do that?

Partner: Bouncy to it.

Partner: Let's line up a bunch of them so they can all bounce around.

Student B: Hold on.

Partner: Line a bunch of them up. You can't control yours.

Student B: See this is that...

Partner: Gravity is down.

Student B: ...go up.

Partner: Yeah.

They also made their pool game with the bouncy property of the dots:

Teacher: You could set up a...you could make this wider and make it a pool game. Right?

Partner: Yeah. I suppose we could.

Other group: That is what we are trying to do.

Partner: Really? You have to have the balls marked different colors though. For the, like, one side it'll be all green and for the other it'll, like, be all black to distinguish solids from stripes.

Student B: Just repeat them.

Similar to student A's case as we discussed earlier, when given the control of their learning paces, students were more engaged in their learning process.

Both groups in the case studies were lost when they were in Module 2. Although there were instructions from the ThinkerTools package prepared by the teacher, students were still lost when they were setting up their experiments. The instructions led students to set up their experiment step-by-step using only word descriptions. Student needed to find the option and menu that were described in the instructions. It is possible that students needed more time to translate the description of the instructions into the symbolic items of the options (radio button, checkbox, and sliders) and this frustrated them. It would be better if the instructions could show more visuals to help students understand where to find those options on the screen. When they needed to measure the distance, it was hard for students to control the cross-hair (+) to measure the distance between every two dot prints by using the touch pad of the laptop computer. Another issue as discussed above is that the instructions taught students to "Pause" the dot before it stopped by sliding friction (Module 2). Sometimes students did not notice that the sliding friction would eventually stop the dot, because they paused the dot

too early before the dot prints showed the dot print pattern of the motion. More examples can be found in the activity of Module 3 and are discussed in a later section.

When students were trying to turn the dot at the corner in Modules 4.1 and 4.2, they experienced that the dot did not turn right away in the expected directions. Then they realized they either had to stop the dot (Student A) or slow it down (Student B) in order to turn the corner. Therefore, the concept of momentum was taught implicitly in Modules 4.1 and 4.2.

Module 3 (Mass and the Effects of an Impulse, Design of Computer Experiments)

Student A

At the beginning of this activity, student A and his partner had to write down their hypothesis.

Student A: What's our hypothesis?

Partner: Because if the mass is greater then something will happen and ...

Student A: If the mass is greater, then what?

Partner: Like it makes more dots in that trace.

Student A: That makes sense.

They related their experience of ThinkerTools to their hypothesis. For example, they started to use dot prints to represent the motion of the dot, "*Like it makes more dots (trace) in that....*" They also realized that they needed to control one variable (impulse) in order to test their hypothesis:

Student A: Are we just described or are we going to use this to carry out our experiment? I don't know.

Student A: We move the dots to the side.

Partner: We did it through give it two impulses to run and watch it.

Student A: Gave each one impulse to move it.

Partner: Yeah, we did it two. That was two impulses.

Student A: Do they have the same number of impulses?

Partner: Yeah! Two positive impulses.

Partner: And wait until it hit the x

The instructions guided them to drag a wall to stop the dots but they set up a target to stop the dots, which showed that they did not pay enough attention to the instructions. In the end of the first module (The Impact of Mass on Motion), student A and his partner reached their conclusion and wrote down their law:

Student A: Did your data support any of your hypotheses?

Partner: Yes. Because this one took more time.

Student A: Cause the higher mass one took longer and adds more impulses.

Student A: What is the law? The higher the mass, the more impulses they are.

That's the law.

Partner: The higher the mass, the slower it moves?

Student A: Yes.

When concluding their observation simply from the screen output, they both understood the relationship between mass and impulse. However, the task evoked a conflict between the students' everyday life experiences and the simulation experiences. When they tried to relate their findings to real life experiences, their discussion helped them adjust their conception:

Partner: A bowling ball will go slower than a ping-pong ball. A thing like that.

As they get the same push.

Student A: Aren't they going to go the same?

Partner: No, cause it has more mass than the Ping-Pong ball.

Student A: When you push a ball in low, we have to give it like a weight, 10 ponds bowling ball.

Partner: OK, actually it's mass.

Student A held the misconception in the pretest that balls with different masses moved at the same speed when given the same impulses. In their conversation above, student A stated not only his misconception as in his answer for the pretest question, but also showed his confusion about the difference between weight and mass.

In the Module 2 activity, students were guided and given the chance to change different types of frictions (sliding and air/fluid frictions) for the simulated environment, and

then they compared the motion of dots with different masses. The friction environments in the Module 2 program helped student A experience motion under the constant effect of friction. During this activity, he found a pattern to the change of the dot prints left behind the dot, and he realized that the dot's velocity was decreasing. The pattern showed in his conversation was, "...1.25...no...how high does it go? 3.75...3.25...2.75...2.25...." By giving the dots the same impulses and releasing the dots, they could then compare the relationships between mass and the two types of frictions. Like most of the students, the phenomenon that the dot with more mass stopped earlier than the dot with less mass seemed familiar to student A because he and his partner had no conflict/question during this part of the activity according to our observation.

When the friction was switched to air/fluid friction, the result showed that the dot with less mass stopped earlier than the dot with more mass. In sliding friction, the heavier mass slows down faster because the friction is greater than with the lighter mass. In air/fluid friction, the surface area determines the resistance and since there is no option in ThinkerTools for students to change the shape (surface area) of the dot, the friction is constant and the momentum of the heavier mass is greater (if the velocities are the same). These relationships are difficult to see, envision, and understand.

The scenario in motion with air/liquid friction posed questions that prompted student A and his partner to suspect and compare their results to the results in the sliding friction activity. In the end, they both noticed the difference between sliding friction and air/fluid friction:

*Partner: Ok we just say that: with air resistance, it's the opposite because the higher the mass pushes against ... the opposite of the sliding friction.
(Teacher asking: have you tried more fluid friction or less fluid friction?)*

Student A: It's slowing down but it's slowing down a lot.

Partner: But this one keeps going this one stops. Because it has more force against the friction to it.

(Teacher: Interesting, so it's just the opposite of what the sliding friction is?)

Student A: With fluid friction, the higher the mass, the longer it last.

Partner: that's fluid friction.

The answer in student A's homework showed their conclusion for this activity:

"It is the opposite of the sliding friction. The higher the mass, the faster it will go and last. The lower the friction, the faster it will slow down and stop. With gas/sliding friction, the higher the mass, the longer it will last."

However, as mentioned earlier, the shape/surface area has something to do with air/fluid friction. Students simply stated, *"It is the opposite of the sliding friction..."* and *"...With gas/sliding friction, the higher the mass, the longer it will last."* It does not mean that students really understood the principles of air/fluid friction since they did not have the chance to investigate the relationship between the shape of the object and the friction.

Student B

From their conversation during the Module 2 activity, student B's partner's misconception showed because he believed that mass does not affect the impact of friction:

Student B: We can do like three different impulses.... Two dots on the screen, one dot above the other. Make one bigger (on mass) and one smaller.

Partner: Well it doesn't matter; if we got there it won't make a big difference.

In this case, the teacher designed her own questions instead of using the questions from the ThinkerTools package to guide students through their experiment. These questions evoked students' alternative conceptions by asking them to state their research question and make their hypothesis as the questions in Module 3 activities.

Like student A, student B and her partner were confused by the setup procedure and they first encountered the problem of setting up a target/wall for their dots to hit:

Student B: So you know how long it takes to stop which will take longer or go faster.

Partner: Yeah but you have to have a target so...

Student B: We'll make a target.

Partner: There is no target. We have to measure too. We have to reach the target so...I will give them three impulses.

Student B: Give dot no.1 three impulses

Partner: And time. It doesn't make sense. Because it can't like go ... it has to have a target.

As discussed earlier, they probably used their experiences from Module 1 and believed that the dot needed to hit the target or wall to be stopped. The instructions for the first part mentioned setting up a wall to stop the dots, here again showing that students did not seem to pay attention to the printout instructions. As a result, they then tried to increase the friction rate in order to stop the dots before they moved off of the screen:

Partner: This one doesn't seem to stop.

Student B: Hold on.

Partner: It's not going to stop.

Student B: You have to make a wall.

Partner: We should change the friction rate.

Teacher: First you want to keep the friction the same.

Partner: I know, there is no friction on the first it's not going to work.

Student B and her partner were confused by how to stop the dots and tried different amounts of friction. When they figured out the proper friction rate to stop the dots, they encountered the problem of how to set up the program and collect their data automatically. The first part of this activity was supposed to be set up as a frictionless environment. How to set up a data table to automatically collect data was also mentioned in the instructions. At the end of class, they had not collected any data that was needed for their homework. It is possible that the descriptive nature of the instructions did not draw students' attention to read through its content. They spent most of the class period setting up the experiment and asking for help from their teacher.

These modules were selected by the teacher in order to fit in a shorter time period for this unit. It would have been better if the teacher could have set up the properties for the selected modules and save the files for students to use if time constraint was an issue for a shorter unit using ThinkerTools package.

In the second part (The Relationship between Mass and Friction), student B seemed confused by the relationship between mass and friction. Her partner corrected her statement and then they reached their conclusion:

Student B: Maybe we should put the friction on lower...on .8.

Partner: The higher the friction...

Student B: No, the higher the mass...

Partner: The bigger the mass...

Student B: ...the less velocity or something...

Partner: You have to have friction, too.

Partner: No...because the bigger the mass the more the (sliding) friction to the object.

Student B: What?

Partner: The bigger the mass, the more friction it has.

Partner: Okay, you said here, the smaller the mass of an object, the bigger the velocity has--assuming that they have the same force... You need to say that.

They measured their data by using the measuring tool although the teacher taught them how to set up their data table to collect data automatically by the end of previous class period. Then, with the help from the group members in the next group, they figured out how to set up a data table and a timer to collect the distance between every two dot prints and time spent:

Partner: How are you supposed to measure those little tiny dots?

Student B: Which ones? These?

Partner: Yes.

Student B: I don't know...

Partner: What did you do?

The other group: Go to Measure...then go to Show Data Table...

Partner: Yes, but that doesn't show it.

The other group: It shows the total...

Partner: How come the time is all wrong?

The other group: You didn't have a certain target, so it just goes on until it stops. Do you have a friction that's....

Partner: So this will be after 1 second, 2 seconds...2 seconds is ----- distance, then it starts decreasing?

Students needed sufficient time to finish a module. In student B's case, they were not able to recall the knowledge that they learned just two days ago and spent the same amount of time learning how to set up their experiment.

In the last task (air/fluid friction) in Module 3, they realized how to set up all the variables for their experiment. The results of their experiment caused a conflict between the results and their experience with sliding friction:

Student B: The smaller mass it has, the more coefficient is ... I don't know why, but what we did was...

Partner: We had our greatest mass...

Partner: We had a dot with the mass of 4, we had a dot with the mass of 1, then we added like 3 impulses to each then ... each...like the red one...we gave it smaller mass, so it stopped at a certain point and then the other one was still...

Student B: Yea, the one with the greater mass went further?

Partner: Yea.

Student B: So, yea, the greater the mass from the object, the more slowly it slows down.

At the end of the activity, they reached an agreement from their understanding that the dot with greater mass would go further under air/fluid friction and made their conclusion on the results of their experiment, "*The greater the mass of an object, the longer it takes for it to slow down with gas/fluid friction.*" In student B's answers for Homework 4, she wrote, "*The greater the mass of the dot, the faster it will slow down with sliding friction*" and "*The greater the mass of an object, the longer it takes for it to slow down with gas/fluid friction.*"

Again, like student A, student B and her partner concluded their findings by simply stating the relationship between mass and air/fluid friction. The program showed the dot with

greater mass moved farther under air/fluid friction, which is correct only when the two dots have the same shape/surface area. However, the concept of momentum was not taught explicitly in the ThinkerTools package and students were not given the chance to discover the relationship between shape/surface area and air/fluid friction. This result in this part of the activity would possibly build an alternative conception of a student's understanding on air/fluid friction. The situation was also found in Rieber's (1991) study; he found that the gravity-less environment of the simulations allowed students to construct a misconception. Therefore, he suggested that guidance is necessary to avoid the possibility that students might construct such misconceptions. In these cases, the teacher might need to explain the impact of the shape/surface area on air/fluid friction and explain that it was the momentum that made the heavier dot move farther when the dots have the same shape/surface area under air/fluid friction.

Posttest

Student A

In the posttest student A answered all of the focused questions that tested students on the same concepts as in the pretest questions (4, 6, 7, 12-14, 20, 23-26, 27-28, 29-30, 35, and 36) correctly. When comparing Question 29-30 (a ball is moving in a circular track, predict its path when the wall of the track suddenly disappear) to Question 9 (predict the path of a ball shooting out a "C" shape tube) in the pretest, student A improved on the concept of inertia (First law of motion). In the pretest, he believed that the ball shot from the end of a "C" shaped tube would move in a curved path. He corrected his belief of the same concept in the posttest question, *"It would go straight out wherever the hole is made."* Since he had less

difficulty understanding the meaning of the patterns of dot prints, no significant difference was found between the pretest and posttest on this concept. Question 36 asked the same question as Item 13 in the pretest (two balls that were hit horizontally with different sizes of impulses and released at the same heights.). Student A improved his understanding of the pattern of falling objects with horizontal momentum, because he could explain his answer correctly in Question 36, *“Because the projecting motion does not affect when an object hits the floor since they were released at the same time they would hit the floor at the same time.”*

Student B

Student B also answered all the focused questions (4, 6, 7, 12-14, 20, 23-26, 27-28, 29-30, 35, and 36) correctly. Possibly because she answered Question 9 (a ball shoots out of a “C” shape tube) in the pretest correctly, she, therefore, had no difficulty answering question 29-30 (predict the path of a ball that was moving out of a circle track) correctly. Student B answered Items 1, 10, and 11 (dot print concept) in the pretest incorrectly. In question 35 of the posttest, which asked students to make dot prints to show a dot speeding up and slowing down, she answered correctly and explained reasonably, *“The dots are made every second, then the ball is traveling a distance between each dot when it's going fast, and not as much distance is covered in one second when the ball is moving slow.”* Her explanation showed her understanding of the concept. Question 36 asked the same question as in Item 13 of the pretest. Student B did not explain why she chose the correct answer in Item 13 of the pretest. From her explanation for Question 36, she clearly stated her understanding of the gravitational motion with horizontal momentum, *“C, they both have the same amount of gravity and air resistance acting on them while they are free falling.”*

Although there were questions from both the pretest and the posttest that could be used to compare and measure student performance, only a few questions in the posttest had a connection with the ThinkerTools package. The teacher chose the pretest and the posttest questions in order to match her instructional goal of this unit; therefore, only a limited number of questions were valid for comparing student performance. For example, when comparing student answers for Question 35 of the posttest to the answers for Items 1, 10, 11 of the pretest, we found that most of the students drew the correct dot print set to represent a dot's motion in the posttest question than in the pretest questions. It showed that student performance on the dot print idea, and the dot print concept were essential in the ThinkerTools program. However, the rest of the questions that that were discussed and compared in the case studies had little connection with the ThinkerTools modules that were used in this unit. This result weakened the validity of the posttest questions and made it hard to measure student performance using the pretest and posttest questions.

In these cases, student A seemed to gain more from using the ThinkerTools program than student B. Conceptual change and understanding of physical concepts such as the resulting impulse from impulses in 90 degree directions and the relationship between mass and impulses could be found from the interactions between student A and his partner. These types of instances were seldom found from the conversations between student B and her partner. During Module 2 activities, both students concluded that the more mass a dot has, the faster it will slow down under sliding friction since the simulation generated the scenario that was clear and similar to students' everyday experience. However, the questions designed by the teacher for the second part of the Homework 4 activity (Module 2, Relationship between Mass and Friction) simply guided students to explore the different outcomes of the

relationship between mass and different types of frictions. ThinkerTools didn't give students the chance to test the influence of the shape on air/fluid friction; furthermore, no posttest question tested the students' understanding of this concept. Also, the teacher did not implement the follow-up activity on air/fluid friction from the ThinkerTools package. Therefore, simply stating their observations and identifying the different outcomes of their experiments on sliding versus on air/fluid frictions didn't mean the students understood the concept of motion and air/fluid friction. For a middle school student, the air/fluid friction concept might be too advanced to understand. More guidance and maybe instruction would be needed if Module 2 is to be used in this unit.

Discussion

This study was designed to explore three major research issues. In this discussion, I analyze, in turn, how the available evidence speaks to these issues. In addition, the present findings are related to the available literature, the limitations of the research are described, and directions for additional research are suggested.

The first research issue was to explore, in depth, how students used ThinkerTools and to explore how their use influenced their understanding of Newtonian motion and kinematics. Overall the results suggest that students benefited from their use of ThinkerTools in this context.

A number of lines of evidence support the conclusion that students' understanding of Newtonian motion and kinematics was improved by the use of ThinkerTools. For example, there was student growth in interpreting dot prints representing the motion of an object. In their answers and explanations to the pretest questions, many students could verbally

describe the motion of the dot correctly, but picked the incorrect dot print sets to represent their interpretation. This pattern of answers indicated that possibly more than 50% of the students could not translate their verbal representation of motion into a visual representation. When their explanations for their answers were analyzed, we found that students interpreted the frequency of dot prints per unit distance to measure the dot's velocity. These students had difficulty relating their experience-based knowledge and verbal representation to the dot print sets when motion was represented in dot print sets.

The footprint questions in Homework 1 helped students transfer their everyday experience in learning this concept. From their own walking and running experience students could imagine how footprints would appear as a person moved faster or slower. Interpreting the dot print left by a moving dot was more unusual than interpreting a person's footprints. Their knowledge and understanding of marks left by a moving object were "situated" in the footprint context. The students' inability to transfer their "footprint" knowledge to the ThinkerTools environment is an example of situated cognition as described by Brown, Collins, and Duguid (1989). Use of the footprint example in the homework may have helped some students create meaning to the relationship between the change of distance between marks dropped at a regular rate and promoted transfer from their knowledge of a day-to-day real life situation (footprints) to the more unfamiliar situation of dot prints. The follow-up activity (a video showed students a billiard ball that was bonked) made connections between students' footprint experience and the dot print experience. This strategy of moving from a familiar example to an unfamiliar one is akin to Clements' (1982) bridging analogy strategy. Students' ability to correctly describe the motion of the billiard ball from the dot prints left behind suggested that students realized the meaning of the dot print set. They projected their

prior knowledge from the footprints and filled in the dot print pattern of motion using their prior knowledge and perception (Blich, 1989).

As contrasted with the lower level of performance on the pretest, thirty-two (91%) students drew dot print patterns and explained their answer correctly on posttest Item 35 showing that students did improve their understanding after the ThinkerTools activities.

As they came to be understood, the dot prints served as a useful tool for students to interpret other situations. For example, this conversation between two students investigating the effect of mass and impulse on motion reveals that the dot prints played an important role in the ability to interpret their experimental results.

Student A: What's our hypothesis?

Student B: Because if the mass is greater then something will happen and ...

Student A: If the mass is greater, then what?

Student B: Like it makes more dots in that trace.

Student A: That makes sense.

This interaction shows that, at the end of this study, students were used to relating dot print patterns to the speed of the dot.

In the ThinkerTools package, for many students, understanding the dot print idea was not promoted by simply demonstrating the dot prints left by a moving dot in the software. Rather, understanding of dot prints was actually achieved by the assistance of the accompanying materials and activities, such as homework, demonstrations, and hands-on experiments.

Data cross representing the velocity of an object

The data cross is a key component in the ThinkerTools package that helped students understand the motion of an object. The data cross provided a visual representation of the velocity of the object and the number of impulses applied to an object. The arm of the data

cross on which the visual representation appeared indicated the direction of the applied impulse and subsequent velocity. The number of units from the origin represented the speed and number of impulses applied (because each impulse, with the standard mass dot, produces an increment of 1 on the speed scale). As students learned to interpret the information delivered by the data cross they came to better understand aspects of the principles of motion. In particular, the data cross was helpful in allowing students to understand that to stop or change direction of the dot, impulses equivalent or greater in number to the original impulses and in the opposite direction to the original impulses had to be applied to the dot. In other words, the impulse required to stop the dot, once in motion, had to be equivalent to the impulse that put it in motion, but in the opposite direction. The data cross also was intended to help the students decompose motion into vector components.

Evidence that the data cross functioned in this way is provided in the data. In the Module 4.4 activity and homework answers, students had to program the data cross with “stored” impulses and then apply the impulses simultaneously by pressing the space bar in order to hit a target. The students were quite successful in this task. Their performance showed their proficiency in giving impulses in right angle directions to move the dot to hit the assigned target. These cases showed that they were able to predict the direction of the motion that resulted from impulses applied in right angle directions. The data cross served as a visual representation of the impulses programmed.

No posttest questions tested student performance on their understanding of the data cross concept. However, when we interviewed the ten students and asked the students to describe the motion of a dot according to the information on the given data cross (Appendix C, Item 8), all the students could describe the direction of the dot correctly. These results

show the improvement in students' understanding of data cross idea. The questionnaire results (Item 7) and students' feedback also show that most of the students agreed that the data cross helped them to understand the difference between velocity and speed. In questionnaire Item 7, 61% of the participants either felt that it was true or very true that the data cross helped them to understand the difference between speed and velocity. Twenty-three (66%) students answered for open-ended question Item 7 that they realized the data cross provided information about velocity and speed. While the data cross was a useful tool, their understanding of the resulting velocity was limited to the direction of resulting velocity. When asked to compare a dot with five impulses downward and a dot with both three impulses in the two directions at right angles, most of the students were not able to correctly predict which dot would go faster (Homework 4, Question 5). In Homework Question 5, the resulting impulse of the dot with both three impulses in right angle directions was approximately 4.2. It was not easy for students to tell the difference between a dot with a speed of 5 and a dot with a speed of 4.2 in the simulation. More diverse examples such as a dot with five impulses from both right angle directions could be included in this question to emphasize the difference. Some of the students simply added the impulses from different directions to obtain the resulting impulse/velocity rather than using the Pythagorean to calculate the vector. Given the age and educational level of the students this is not surprising. Some students were not able to realize the quantitative difference between horizontal velocity and velocity in a diagonal direction:

Student 2: So you think it's going the same speed?

Student 1: I think it's going faster.

Student 2: ...same speed...

(Predicting the velocity of a ball with forces in right angle directions)

I don't know what you're doing wrong, but look at that. Go back to the

beginning of the maze... Make it go diagonal. Look, it speeds up.

It takes more knowledge of vector addition to calculate the magnitude of the resulting velocity. When students did not have the required advanced knowledge to understand the concepts behind the simulations, the impact of the use of simulation seemed to be tempered. Similar to the strategy used in the footprint questions in Homework 1, it would be helpful for students to understand this concept if some workbook activities could be included in the ThinkerTools package. Students could start from drawing and comparing the magnitude of the resultant impulses on the worksheet and then use the simulation to test their results. These activities could possibly help students realize the quantitative difference of the resulting impulses.

Graphing the motion of an object

Questions 8 and 9 of Homework 2 were the only graphing questions that tested students' understanding of how to represent the motion of a dot in the form of graphs. More students (12) provided incorrect descriptions for Question 8 than for Question 9 (7 students), suggesting the possibility that it was harder for students to interpret an object's velocity from a graph than to translate a descriptive message into a graph. However, the wording in Homework Question 9 is presented in a more detailed and more complex manner than the wording in Question 8. The difference in performance suggests further study on the design and wording of test questions as well as additional study on students' understanding of graphs. Graphs are an important tool in science, and rich literature on the development of understanding of graphs exists and on their function as a tool for scientific analysis is developing (Friel & Bright, 1995; Fisher, 1992; Dibble & Shaklee, 1992).

The numbers of the students who correctly answered the graphing questions on the posttest were: Item 23 (positive acceleration) 30 (86%), Item 24 (standing still) 35 (100%), Item 25 (negative acceleration) 35 (100%), and Item 26 (constant speed) 31 (89%). Compared to the results of Homework Questions 8 (66%) and 9 (80%), the improved performance on the posttest seems to show the improvement of students' ability to select graphs depicting the motion of an object. However, the improvement is more likely due to the homework tasks and in-class discussions rather than software itself. Thinker Tools does not provide graphs directly, but provides students with data tables that can be graphed. The homework assignments asked students to graph the data tables and to draw conclusions from them (look for patterns, etc.). Most of the homework questions required students to accomplish their tasks with the computer simulations. Thus, ThinkerTools, combined as part of a package, may have contributed to increased learning.

The impact of impulses on the motion of an object

On Pretest Question 10 (predict the path of a coasting rocket after it fires a thruster), 12 students predicted that the rocket would change its direction right away (turn 90 degrees) and 13 students predicted that the rocket would move in a curved path. Interestingly, the form of pretest Question 10 may have also contributed to students' problems with the question. The graphic in Question 10 was the rocket coasting horizontally, and then moving toward the bottom of the page after the thruster was fired briefly. The situation is visually similar to examples of falling bodies where the acceleration of the thruster is not temporary, but is the constant acceleration due to gravity. Thus, the visual similarity and the direction of the rocket's movement on the page may have misled students to interpret the problem situation according to their experiences with falling objects that have horizontal momentum. Such an

interpretation would have led them to choose answer “C” (the curved path). Validating this possibility that the design of the question influenced the students’ error rate on this problem would need further study.

On the pretest, students had difficulty relating momentum of a moving object to its direction of motion after an impulse is applied. For example, Questions 12 and 13 on the pretest asked students about the direction an impulse should be applied to a moving hockey puck to make it turn in a track. At the first turn of the track, only 9 students took into account the effect of inertia, while the others seem to consider the puck’s momentum and believed that an impulse that hit the hockey puck in the direction of the track (45 degree turn) would keep the hockey puck on the track. Most students used the same wrong interpretation for turn 1 and turn 2. These examples from the pretest make it clear that many students had difficulty understanding the effects of momentum, especially when the momentum or impulse was not exerted in the direction of the dot’s movement. The low percentage of students correctly answering these questions suggests that students had difficulty in combining momentum and applied impulse in determining the object’s motion. It is possible that students did not see the connections between their real life experiences on momentum and the scenarios described in the pretest questions.

The ThinkerTools package provided experiences that helped the students construct the theoretical principles involving the combination of momentum and newly applied impulse. In Module 4.1 (Turn a Corner) and Module 4.2 (Run a Maze) activities, students experienced the impact of the inertia/momentum when they tried to turn the dot into different directions. The influence of these instructional experiences in the ThinkerTools environment is shown in their answers to the questions in the follow-up homework (Homework 4,

Questions 1, 2, and 3). In contrast to their performance on the pretest, more than 75% of the students were able to visualize correctly the directions of impulses that would turn the dot into different directions and predict the dot's paths. According to in-class observations, in the class discussion that occurred right after Modules 4.1 and 4.2 activities, all three students picked by the teacher could draw the impulses on the blackboard and explain them correctly. Also, in the students' answers for interview Item 7 (Appendix C), when given a printout of a maze showing a dot at the entrance of the maze, all the interviewees were able to verbally present how they would they give the dot impulses to make it turn in a maze and hit the target correctly. Compared to the results of the pretest questions, these findings indicate that students improved their understanding of how momentum and a newly applied impulse combine to influence the future motion of an object.

Mass and the effects of an impulse: What is the relationship?

Relationship between impulse and mass

The ThinkerTools package did not seem to contribute much to students' understanding of the relationship between the mass of an object, an impulse applied to it and its subsequent motion. Pretest Question 14 (impulse exerted on balls with different masses) tested students on this relationship. Twenty-eight (80%) students had no problem answering that the heavier ball would move more slowly when given the same impulse as the lighter ball. It seems likely that students had more relevant everyday life experience on this topic than on other topics. When analyzing the students' discussion while they completed Module 3 (Design Their Own Experiments), several examples of students' understanding on the mass/impulse relationship were found:

“The force will be greater that moved the ball the same distance because the mass is more. It requires more force.”

“...the heavier the object, the slower it will go...show what you learned through this. If you had to do the tractor pull, you’d want to take the one with the less mass.”

Despite having answered correctly on the pretest question, many students incorporated friction into their hypotheses in the Module 3 activity, even though the question did not involve friction. These students developed a hypothesis that was equivalent to the following: *When impulses are applied to an object, the more mass the object has; the more friction will affect its motion and therefore the object will move more slowly than an object with less mass.* This result suggests that students based their hypothesis and understanding of the mass/impulse relationship on their everyday experience in which friction is always present. Because the dot that had more mass did move more slowly than the dot with less mass in their experiments, all of the students concluded that their results did support their hypotheses. In this case, the ThinkerTools activity potentially contributed to the strengthening of a misunderstanding. One way that this problem might be avoided would be to incorporate a ThinkerTools activity that would lead student to directly contrast the motions of dots of different masses on friction and frictionless surfaces.

Relationship between friction (constant force) and mass

Students were tested on the concept of sliding friction in the pretest. Most of the students (80%+) answered and explained correctly the relationship between mass and sliding friction for these questions (Item 10 and Question 15). These results show that students had more everyday experiences with the concept of sliding friction that helped them answer these questions correctly.

The ThinkerTools activities used in this study had students investigate sliding friction and air/fluid friction. While some of the students did observe differences in the behavior of the dot in these environments, the distinction between these environments and the way they were expressed in ThinkerTools may have also led to some students' confusion.

In the Module 2 activity, students set up friction experiments and tested the dot's motion in two friction environments. The prints left by the dot showed the pattern of the dot's velocity change. Students could find the pattern of the change in the dot's speed when they measured the distance between dot prints:

I think I know what the pattern was supposed to be...it's supposed to be...3.75, 2.75, 3.25, 2.75, 2.25, 1.75, 1.25, then .75, then the next one will be .25.

...go to run...pause...go to pause then you do this...on the first page...Are you noticing what I'm noticing? 2.75...I'm seeing a pattern here...I don't know about you.

The dot print patterns and their analysis of the distance between them helped students understand the impact of sliding friction on an object's motion.

In the second part of the Homework 5 activities, students also were asked to investigate the effects of friction. In the first part of the activity, they tested sliding friction. First, they used the Module 2 program to set values for friction for a surface the dot would slide on, and then tested the motion of the dot. Next, they changed the sliding friction to air/fluid friction and tested their experiment again. Most of the students (83+%) understood the relationship between sliding friction and mass. Their conversation showed their understanding:

*So the higher the mass, the faster to stop with friction.
Yeah. You never call it a law.*

*The one that has the bigger mass.
Because there is more friction.*

When the friction was switched to air/fluid friction, there were times that students were confused by the motion of the dots.

That's what we had, too, I think. Oh, my...it's going to crash. It (the heavier dot) won't stop moving. Stop! Teacher, how do you make the dot stop? We have it on the air resistance friction, and it won't stop.

They believed that a dot with more mass would stop earlier; however, the dot did not behave as they expected. The conflict possibly was either from their everyday experience or from the first part of the experiment (sliding friction). Some students even believed that there were some problems with the computer:

*Teacher, we screwed up.
This is really stupid. I have (air) friction on, but it's all screwed up. It doesn't stop. It's on 50 kg and it's still going on an impulse of 1.*

*It's supposed to stop right away.
There's something wrong with the computer. Okay, what law?*

Students eventually noticed the impact of the air/fluid friction and sensed the difference between sliding friction and air/fluid friction:

*Teacher: Does that surprise you?
Yes. Because it kept on going for a long time.
What did I miss?
All this...you missed a lot...all this...
The more the mass, the longer it rolls...*

*Are we going up to seconds?
Sliding friction has more friction?
Actually it has less...gas friction has more?
No it doesn't, because it keeps going.*

From their answer for Homework 5, we could find student responses such as:

"It's almost the opposite of what sliding friction does, the one with less mass slows down and stops first and the one with more mass keeps going because it has more

force against the air resistance. With fluid friction the higher the mass the longer it will stay moving."

The air/fluid friction computer experiment showed students a result that was different (reverse) from the result in the sliding friction experiment. Clearly, these latter students observed differences in the behavior of the dots between the sliding and air/fluid friction experiments. These observations may ultimately be useful in their developing an understanding of kinematics.

However, the variables that influence sliding and air/fluid friction are complex. The sliding friction force depends on the coefficient of friction for the surfaces. For air/fluid friction, increased mass does not increase friction so long as surface area is constant, but does increase momentum. Disentangling these relationships may be too advanced for eighth grade students. The simplified simulation provided by ThinkerTools might help students perceive that there is a difference in the way friction works in the two situations, but does not provide enough information for students to fully comprehend the principles of these types of friction. Therefore, this activity might be considered inappropriate for middle school students. In addition, the questions accompanying the Module 2 program were not picked from the ThinkerTools package. These questions were integrated by the teacher to guide students to explore the difference between sliding and air/fluid frictions (see Homework.pdf in the accompanying CD-ROM, Appendix E).

The ThinkerTools package provided guidance for following activities in helping to explore the phenomenon of air/fluid friction. Simply having students experience air/fluid friction through simplified computer simulations could endanger students by helping them build alternative conceptions. More details will be discussed in a later section.

There were no posttest questions that tested students on their understanding of friction. Therefore, only the in-class observations and the student homework provided insight into the students' understanding of friction.

The ThinkerTools helped students experience the principles of motion that might not be familiar to them, and thus made connections between the science concepts and students' prior knowledge. By the end of this unit, students benefited from exploring the scenarios that were provided at the simulations and the accompanying materials and activities.

A second major purpose of this study was to assess students' attitudinal reactions to the ThinkerTools software package as an instructional tool. Students are unlikely to generate positive motivation for the future study of science if their science experiences lead them to conclude science is boring, frustrating, or unmotivating. Part of the potential value of software such as ThinkerTools is that, used appropriately, it can facilitate learning and also promote positive motivational outcomes.

Conceptual conflict

Sixty-two percent of the total participants answered Item 8 of the questionnaire that using ThinkerTools challenged some of their previous ideas about how motion works. Most of the students provided positive responses in their answer to the open-ended questions. When being asked about what was the most important thing that students learned from using ThinkerTools, most of them mentioned the relationship between mass and force, mass and friction, and mass and velocity. One student mentioned that ThinkerTools raised conflicts about her prior understanding of motion:

"From using ThinkerTools, the most important thing that I learned was that the ball does not behave the way that a person would normally expect it to behave. This helped me learn a lot of concepts."

Two additional students also expressed the same idea, that with ThinkerTools, they experienced objects moving in unexpected ways.

“If you push something it doesn't want to stop.”

“You can never be too sure about what you assured.”

The students' answers to Item 12 in the questionnaire also indicated that 67% of the participants had experiences with ThinkerTools in which the dot did not behave the way they expected it to behave. Thus, this supports the results from our observations of the students that ThinkerTools did raise cognitive conflicts with students' prior beliefs. Another example of how ThinkerTools created conceptual conflict involves the activities in which students programmed the data cross to provide impulses to the dot in order to hit a target. In those activities, as discussed above, the dot did not always move in the path the students expected when the programmed impulses were applied. The unexpected movement caused a conflict with students' beliefs. One of the other students mentioned the same experience when being interviewed:

“I think... the velocity. Because at first I didn't really... you know... like an upward force and the force going cross... I thought it would like the first one would be cancelled out. But it makes it go diagonally, so I think it's kind of an important thing.”

Eighty-three percent of the total participants felt the scenarios that ThinkerTools provided were reasonable (Questionnaire, Item 13). This result suggests that the simulations made sense to most of the students and students seemed to see the experiences as credible and applicable to real life. The responses of this item also showed the possibility that the ThinkerTools package corrected students' alternative conceptions.

Positive responses

In general, the questionnaire results (Items 10 and 16) show that most of the participants (75+%) liked using ThinkerTools and would like to use the program as a tool for learning physics again. From their answers to questionnaire items (Items 1 and 3), the information provided by the simulations was easy for students to understand. More than 78% of the total participants had no problem understanding the information delivered by the software. Student answers for the third open-ended question (What are the best features of ThinkerTools?) showed that almost half (49%) of the students liked the fact that ThinkerTools allowed them to change the properties of the dots, the environment, and to design their own experiment. Students were interested in using ThinkerTools to take control of their own pace of learning. Seven students felt that ThinkerTools was easy to use; also, four students saw the program as a game. In the rest of the student answers, one student enjoyed the user-friendly interface of the program, and another felt the activities were close enough to the real world experiences. When I interviewed the ten selected students, I found similar results. Six of the ten students liked the features of setting up and designing their own experiment. The other students thought that ThinkerTools was easy to use. Taken as a whole, these data indicate that, as used in the present study, ThinkerTools provided an environment that students found interesting and motivating. Another source of motivation may have been the collaborative pairing of students as they used ThinkerTools. While collaborative learning is not unique to a computer simulation environment, ThinkerTools provides an environment that focuses and guides some of the students' interactions. For example, the activity of designing their own experiments also promoted interactivity between group members. These interactive discussions facilitated improvements in understanding. *"No, it's not all right. This*

one is a heavy ball and light ball will both not...like...okay, see, they both stop, but you notice...a light ball with a high friction will travel more than a heavy ball with a high friction.” My observations of students in the classroom also indicated that the collaborative use of the software encouraged students to express their interpretations and develop ideas about physics principles during their discussions. The students corrected each other, debated points, and when they reach agreement, gained understanding of physics principles. There are 60 interactions between group members that were categorized as students showing their understanding. Below are some examples:

Student 1: What's our hypothesis?

Student 2: Because if the mass is greater then something will happen and ...

Student 1: If the mass is greater, then what?

Student 2: Like it makes more dots (trace) in that...

Student 1: That makes sense.

(Module 3, Designing an Experiment to Test the Relationship between Mass and Force)

That's 6 and 2 or 3 and 1...one more...

You actually got the fast one to do. Cool.

We're done

(Module 4.4, Setting up Different Combinations of Impulses in Right Angle Directions to Hit the Target)

The results show that the simulations increased student interactions between group members when simulations were combined with collaborative learning (students working in groups).

Similar results were found in Krajcik, Simmons, and Lunnetta's (1988) study.

Simulations allow students to rerun the program and come to agreement after reflecting on their ideas in group discussions. These observations or findings reflect those obtained by Otero, Johnson, and Goldberg (1999). The program served as a tool to promote

communication between group members about physical phenomena and concepts and also as a simulator that can help students construct a conceptual model of physical phenomena.

Student reactions to, opinions about and attitudes toward the design of
ThinkerTools and problems encountered

The third purpose of this research study was to explore how students reacted to the design of ThinkerTools environment and to identify problems students encountered in using the software. The motivation for this purpose was practical. Studying user problems in using instructional software (or any equipment for that matter) is a critical factor in the improvement of such software.

Question 4 of the open-ended questions asked students what were the worst features of ThinkerTools. Seven students could not think of any “worst” features, but the majority provided responses to the question. Student concerns and frustration were collected and categorized as:

1. *Unclear instructions*: Four students complained that the introduction was not clear enough for them to understand. Four more students felt that it was hard to set up their experiments. The unclear instructions possibly frustrated the four students when they were trying to set up their experiments. When we interviewed the students, two students reported this kind of problem: “*The instructions are kind of hard to understand,*” and “*The instruction is not clear enough.*”

During my observations of the students’ interactions, I noted that, like these two students, some students also expressed concerns about or were influenced by unclear instructions. One student and his partner spent more than half of the class period reading the

instructions and trying to understand how to set up their experiment. Even when they had set up their experiment, they were still confused about how to start the simulation:

Student A: What are we supposed to do after this? Do we have to do this?

Partner: Are we supposed to be recording any of this or do we just do it?

Student A: Make it all zig zaggy. Make a maze or something. Are you going to try two dots? Are we supposed to make another one?

According to my observations, at least one third of the students encountered a similar problem as student A and his partner. Responses to questionnaire Item 6 also showed that 39% of the participants reported there were times they did not know what they were supposed to do while using the ThinkerTools activities. The instructions in the accompanying manual demonstrated the steps of setting up experiments and indicated how to change options and variables in the program. It is possible that students did not attend to the written instructions for Module 3 as well as they might have. Computer users tend to use written instructions as a last resort. One student reported that when he paid attention and read through the handout, he understood what to do in setting up his experiment, *“The worst feature was probably using... doing... the experiment was kind of hard to understand but once you got the handouts (instructions), you knew what to do.”*

The instructions were primarily verbal (see Introduction Printouts.pdf in the accompanying CD-ROM, Appendix E). Perhaps the instructions would be easier for the students to use if more visuals and screen shots could be added to each step of the instructions. Another possibility is to incorporate better directions on screen. Future development of the ThinkerTools package should explore this possibility.

2. Navigation of the program: In some of the ThinkerTools activities, the dot is not bound by a barrier at the edge of the screen. In these activities, the dot can “move off the

screen.” In reality, of course, the dot doesn’t move off the screen, the program simply calculates what its position would be if the screen were bigger. Two students responded that they were confused when the dot moved off the screen. When the dot moved off the screen, these students were confused because they were not able to visualize the motion of the dot. The instructions hinted to students to use the data cross to detect the direction of the dot’s motion. When the dot is moving or still, the data cross visually represents the velocity of the dot. It is possible that these students paid attention to neither the data cross nor instructions. However, it is possible to create situations in which it is very difficult to detect the position of an off-screen dot. For example, if you stop the dot off-screen and forget which direction it was going when it left the screen, there is no means of determining if the dot is to the right or left (or above or below) the visual screen. Some means to allow students to deal with such situations should be incorporated into new versions of such software.

Another trouble spot became apparent through in-class observations. In order to design experiments, students must switch the software to an “edit” mode. To try out the experiment, the students must switch back to a “run” mode. My in-class observations revealed that some students became lost when they were switching between edit mode and run mode while they were designing their experiments.

It was under run. Now what are we supposed to do? What exactly are we experimenting? We need a target. I’m going to guess that’s the target.

What?

Our blue dot isn’t moving.

Oh, you have to go to run, edit mode.

Run, edit mode?

It would be less confusing if the two windows of the two modes could be distinctive from each other. Or the options for the students to set up their experiment (the “edit mode”)

could be on a pop-up window accompanying the main window for students to see the two windows at the same time.

3. *Delay of keyboard response:* One student was frustrated by the delay of the keyboard response when she was trying to increase/balance impulses for the dot, *“The worst feature were the slow reacting impulses from the keys.”* When students were trying to accelerate the dot to hit or stop on the target, they used the keys (“F”, “S”, “E”, and “C”) to give impulses to the dot. The impulse would not affect the dot until roughly 0.5 second after any of the keys was hit. According to my in-class observation, in the activities of Module 1, it was common that students encountered this problem. However, only one student mentioned this problem. The students also reported this frustration during the interviews, *“Well sometimes when you were giving the impulses, it wouldn’t react (the delay of the keyboard?) yeah... they need to be a little faster.”*

As they gained experience with ThinkerTools, it is possible that students became used to this problem. In later modules, the delay problem becomes less important because it is not necessary to control the dot while it is moving. In modules 2, 3, and 4.4, for example, students programmed the dot using the “E”, “C”, “S”, and “F” keys and they applied the programmed impulses by simply hitting the space bar once. From our observations, the delay still existed under the “auto freeze” mode. However, the problem did not seem to bother students in these modules. The use of the “auto freeze” mode might also explain why only 2% of the total participants reported problems in using the keyboard to control the movement of the dots.

4. *Instability of the system:* According to students' answers to the open-ended questions, the unstable integration between the program and the laptop computer frustrated four students. There were many cases in which the program froze or quit without any reason.

"Oh my god! What are we going to get to go then? It was broken. You can go ahead. You are the one who screw it up. Now it stops moving."

The program was developed on older Macintosh systems. When used with newer systems, it is possible that the integration between software and hardware caused the instability. However, this version of ThinkerTools was the most recently available version. It also was not easy to find older computers that were compatible with the program. This problem with the functionality of ThinkerTools suggests the need for further development and improvement of similar instructional materials.

5. *Difficulty in using the laptop computer:* The laptop computers used hand touch pads for pointing devices. Two students felt that it was difficult to use the touch pad to control the program. Other students found it hard to use the touch pad of the laptop to measure the distance between two dot prints in the Module 3 activities (Homework 5, Homework.pdf in the accompanying CD-ROM, see Appendix E). *"I don't like these pad things."* *"Our mouse is too hard to control."* This problem could be easily solved by plugging in regular computer mice with which the students might be more familiar.

6. *Non-stop timer:* In Modules 2 and 3 activities, students needed to measure the distances between dot prints as well as the time that the dot traveled in order to report the velocities of the dots in the data table. ThinkerTools provides an onscreen timer in these modules. However, students found that the timer sometimes malfunctioned when they needed the timer to show the time duration of the motion.

Go to Measure...then go to Show Data Table...
Yes, but that doesn't show it.
It shows the total...
How come the time is all wrong?

Our blue dot isn't moving.
Oh, you have to go to run, edit mode
Run, edit mode
The clock started before we did.

It is possible that, as in the instability problem noted above, the match between the software and the hardware is responsible for the timer problem. Also, it is possible that the software was not programmed and tested thoroughly, which caused the problem with the timer. However, time is one of the necessary elements in the concept of velocity in motion. Although only a few students encountered this problem, the inaccurate timer needs to be carefully avoided by testing the integration between the program and the system before the unit is begun.

Clearly, collecting the students' opinions about the ThinkerTools software and observations of the students using the software proved useful in identifying potential problems that future versions of the software should address. While ThinkerTools has potential as an instructional tool, it certainly also has room to be improved. The design and improvement of instructional products should be informed by observations of actual users and input from those users.

The teacher's role

The concept of Newtonian motion was not taught before this study began. The teacher was highly interested in using the ThinkerTools package in teaching Newtonian motion. The pretest questions, homework, ThinkerTools programs, and part of the posttest questions used in this study were selected from the ThinkerTools package by the teacher.

However, according to the teacher's instructional goal and the timeline of this unit, only part of the whole ThinkerTools package was selected to be used in this study. The teacher also made some modifications to the material selected in order to fit the purpose of her instruction. For example, some posttest questions were selected from other resources (see "Posttest" section in the "Equipment" section) as were some questions in student homework (e.g., questions in Homework 4). The detailed class activities are described in Appendix D. Since the ThinkerTools modules were selected according to the teacher's instructional purpose, the modules were not used according to the sequence in the ThinkerTools package; therefore, the sequences of the modules used in this study was: Module 1, Module 4, Module 2, Module 3, and Module 2. The teacher tried to introduce both one- and two-dimensional motion of ThinkerTools program (Module 1 and Module 4), and then introduce the relationship between mass and friction (Module 2 program). Students then could design their own experiment using the Module 3 program to test the relationship between mass and impulses; meanwhile, Module 2 was used again to test the relationships between mass and different types (sliding and air/fluid) of frictions.

During the class period, the teacher handed out instructions that contained questions selected from the ThinkerTools package. Students followed the questions and the instructions either on the screen or on the printouts to accomplish their task. The teacher also led the discussions on student homework questions during each class period. Homework questions were discussed in the class following the class that the homework was assigned. The teacher guided the class to reach agreement on their homework answers as well as raised more related questions for students to find answers for from the computer program. During the class using computer simulations, when students raised questions, the teacher provided

guidance for students to find their answers from the ThinkerTools programs rather than simply giving them answers. The principles of Newtonian motion were therefore taught implicitly.

Since the whole ThinkerTools package was not used and the sequence of the modules selected did not follow the same sequence as in ThinkerTools package, some of the concepts that the ThinkerTools package tries to deliver was not properly selected. For example, the module that introduces motion with gravity was not selected and taught; further, the supporting material and activities (experiments) were not used when students were testing the relationship between mass and air/fluid friction. Without these supporting materials, the simulations might help students construct alternative conceptions.

Major Conclusions

As a result, ThinkerTools worked successfully as a tool to make connections between students' prior experience and physical principles. Data cross and dot print ideas were the two important elements of the simulations. Students need to understand the information presented by data cross and dot print sets in order to refer the information to the motion generated by ThinkerTools program. Therefore, dot print and data cross ideas need to be introduced at the beginning of the unit. Then with the aid of the accompanying materials and activities, data cross information and dot print sets would become understandable to students.

Students gained experiences that they did not have a chance to explore while utilizing ThinkerTools simulations. As found in prior studies (Zietsman & Hewson, 1986; Gorsky & Finegold, 1992; Weller, 1995), the scenarios generated by the simulations also contributed to students' cognitive conflicts. Supporting strategies in a learning context were found to increase the effect of using simulations to help students understand abstract physics theories

(Rieber, 1990, 1995; Gorsky & Finegold, 1992; White, 1998; Andre et al., 1999). Because the physics principles were supposed to be taught implicitly using ThinkerTools, the accompanying materials (test questions, homework assignments, and instructions) were found to be another component that helped students connect their prior experiences to physics principles and thus enhance their understanding. Integrated with these materials, the simulations became meaningful to students; they may learn more effectively when the instruction anchors learning in situations that are meaningful to the students (Cognition & Technology Group at Vanderbilt: CTGV, 1990, 1993).

This study found that ThinkerTools promoted interactions between group members. When students worked as groups, they expressed their understanding during group discussions, especially when the computer outcome did not match their expectations. As suggested in Krajcik, Simmons, and Lunnetta's work (1988) and in Otero, Johnson, and Goldberg's study (1999), the simulations allow students to redo their experiments and come to agreement after reflecting on their understanding in their interactions. As demonstrated, students' understanding was therefore achieved during the process of interactions.

Based on the timeline and the instructional goals of the teacher, only a limited proportion of ThinkerTools modules and activities were selected. Under such circumstances, one concept (the relationship between mass and air/fluid friction) was found inappropriate for eighth grade students. The variables that influence the air/fluid friction were simplified in the simulation that demonstrated the effect of the air/fluid friction. Some students were found to have developed misconceptions of this concept. Similar to the findings in Rieber's study (1991), the simulation removed the effect of surface area and velocity of the objects, allowing students to construct a misconception on air/fluid friction concept. More guidance

would be needed to avoid having students construct such misconceptions when using the simulations in teaching. Otherwise, more advanced options on the variables that related to the air/fluid friction concepts might be necessary to avoid alternative conceptions.

By reporting their attitudinal reaction to the questionnaire items and the open-ended questions, most of the participants were found to react positively toward the program. The result shows that the participants did not have much difficulty dealing with the interface and the navigation design of the software when using it as a tool in learning. However, this study also found issues that confused students. These problems commonly resulted from the incompatibility between the program and the computer systems, such as the non-stop timer and frequent frozen software. These problems suggested the need for further development of simulations for instructional purposes.

My research suggests that ThinkerTools did improve students understanding of Newton's laws of motion. However, the pretest and posttest questions were selected according to the teacher's instructional goals. The teacher tried to test students on their understanding not only from the ThinkerTools program but also from the assigned reading. The items in both the pretest and posttest were therefore less related to testing the degree of transfer on student understanding. Students' performance in the present study could only be discovered from their homework answers and their conversations regarding their understanding. More discussions with the teacher before the unit begins might be needed in order to gather more related information according to the research interests.

CHAPTER 5: CONCLUSION

In general this study found that students benefited from their use of ThinkerTools in this context. Students' understanding of Newtonian motion and kinematics was improved by the use of the ThinkerTools program. The data cross and dot print delivered the information that student needed to refer to the motion of the dot. ThinkerTools simulations helped students to experience Newtonian principles that they might not have had a chance to explore in real-world environment. With the help of the accompanying materials and activities, students' prior knowledge were then connected to the physics principles and therefore made the simulations meaningful to students. Moreover, ThinkerTools allowed students to program and to set up their own experiments to test and observe the results from the computer outcome. This feature drew students' attention and also motivated students in using ThinkerTools for learning. Through these processes, students' cognitive conflicts were revealed by the simulations and misconceptions were modified by the ThinkerTools package. Moreover, the simulations and the computer activities served as tools to promote interactions between students when they worked in groups. Students constructed their understanding of Newton's laws of motion by expressing their beliefs and reaching agreements in a collaborative learning situation.

However, this study found that more guidance from the teacher would be necessary if the modules chosen from ThinkerTools required more advanced knowledge to understand the concepts behind the simulations. The simulated environment was designed to help students understand abstract theories by simplifying the context for students to focus mainly on the proposed concept. Advanced knowledge behind the simulation needs to be carefully

considered and supporting materials/activities are needed for a systematic package to help students in learning. Otherwise, the simulations would possibly lead students to develop alternative conceptions.

Overall, students were interested in using the ThinkerTools package and were willing to use it to learn physics concepts in further units. Although the developers have stopped updating the software, which could cause minor compatibility issues on today's computer systems, it is still a valuable software package if used with supporting supplemental materials and under the instructor's advice.

APPENDIX A. QUESTIONNAIRE ITEMS

These questions refer to the Thinker Tools software that you used. Please rate each of the items below on the following scale. Circle the number for each item that best represents your reaction.

Very Untrue of Me	Untrue of Me	Neither True or Untrue of me	True of Me	Very True of Me
1	2	3	4	5

1. I easily understood the instructions on the screen while I was trying each activity. 1 2 3 4 5
2. I had no problem in using the keyboard to control the movement of the dots. 1 2 3 4 5
3. The information on the screen was too complicated for me to understand. 1 2 3 4 5
4. The data cross and the numbers on the screen were distracting to me while I was trying the activities. 1 2 3 4 5
5. The trace dots helped me understand the magnitude of the velocity of the dot as well as changes in velocity. 1 2 3 4 5
6. In using Thinker Tools, there were times I felt I didn't know what I was supposed to do. 1 2 3 4 5
7. The data cross on the screen helped me understand the difference between velocity and speed. 1 2 3 4 5
8. Using Thinker Tools challenged some of my previous ideas about how motion works. 1 2 3 4 5
9. The software interface for Thinker Tools was easy to use to navigate through the program. 1 2 3 4 5
10. I liked using Thinker Tools 1 2 3 4 5
11. The scenarios that the software provided are similar to my daily observations of objects' movement. 1 2 3 4 5
12. There were times when using Thinker Tools when the dot did not behave the way I expected it to. 1 2 3 4 5
13. The scenarios that Thinker Tools provided were reasonable to me. 1 2 3 4 5
14. Thinker Tools helped me understand Newton's first law. 1 2 3 4 5
15. I believe that using Thinker Tools helped me to understand more about the principles of motion. 1 2 3 4 5
16. I would like to use the software again. 1 2 3 4 5

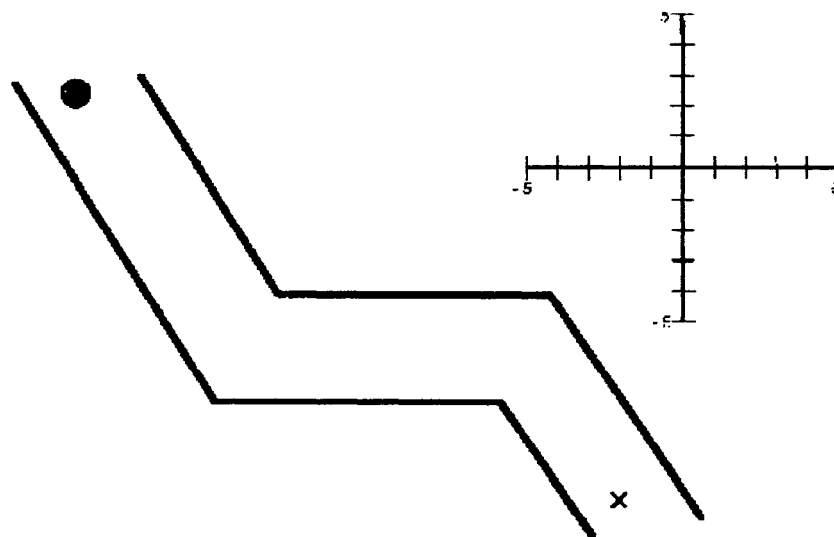
APPENDIX B. OPEN-ENDED QUESTIONS

Please write answers to each of the following questions. Use the back if necessary.

1. What did you feel was the most important thing that you learned from using Thinker Tools?
2. What were you expecting to learn from Thinker Tools?
3. What are the best features of Thinker Tools?
4. What are the worst features of Thinker Tools?
5. Are there any parts of the area of motion that you believe you have difficulty with? Please tell about these areas?
6. Can you explain how Thinker Tools helped and/or hurt you in trying to gain an understanding of the principles of motion?
7. What sorts of information did the data cross in Thinker Tools give you?

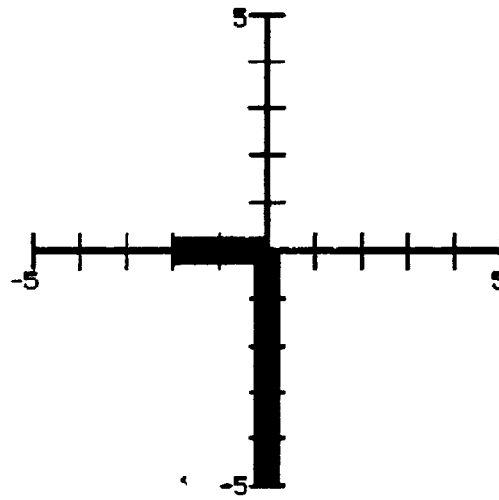
APPENDIX C. INTERVIEW QUESTIONS

1. What did you feel was the most important thing that you learn from using ThinkerTools?
2. What are the best features of ThinkerTools?
3. What are the worst features of ThinkerTools?
4. How do you feel about Physics? Are there any parts of this subject area which you have difficulty with?
5. Can you tell me how you used ThinkerTools to try to make sense of motion?
6. This program is meant to help you improve your knowledge in Newton's law, could you please comment on how ThinkerTools influenced:
 - a. Your general knowledge of Newton's law
 - b. The way in which you approach Newton's law
 - c. The way in which you might apply what you have learn in the future.
7. Here is a sample screen and problem from ThinkerTools. Can you describe what you would do to solve this problem?



Try to hit the target

8. Here is a sample data cross from ThinkerTools, what is this data cross telling you?



APPENDIX D. THE TEACHER'S INSTRUCTION PLAN*The first week*Day 1

1. Pretest (40 minutes): Students answered the pretest questions. After the pretest, Homework 1 (Foot print questions) was given to students.

*The second week*Day 2 – Day 3 (Double period)

1. Opening questions (15 minutes): The teacher asked students to predict the result of a moving ball on a frictionless surface that was hit by a bonker. Several students were selected to answer their predictions and their answers were discussed in the class.
2. Introduction and setups (20 minutes): The teacher introduced ThinkerTools to students, taught students how to use the laptop computers, and guided them how to open the computer programs.
3. Computer activities (Module 1.1 – Module 1.6, 50 minutes): Students experienced the motions of the dot in different dimensions using computer programs.
4. Finishing up (5 minutes): Students were guided to quit the programs and to turn the laptop off for the next class period.

Day 4

1. Discussions on homework answers (15 minutes): The whole class discussed the questions of Homework 1.
2. Motion demonstrations (video, 30 minutes): A videotape showed a billiard hit either just once or with an additional hit when it was moving. Dot prints were showed left behind the ball. Students were required to finish Homework 2 according to their observations from the scenario in the videotape.

Day 5

1. Computer activities (Module 4.1, 4.2, 4.4 and Module 2, 45 minutes): Students experienced the impact of momentum on the dot's motion using Module 4.1 and 4.2. Homework 3 was given to students who would use the computer program to answer the questions. Students were required to find their answers to the homework questions by changing the directions and magnitude of a dot on a data cross. In Module 2 program, students changed the mass and the magnitude of the impulses to test the impact of frictions on the motion of the dot. This activity also prepared students for Module 3 activity because they had to know how to set up the variables of the program to test their hypothesis in Module 3. At the end of the class, Homework 4 was given to students for their reflections on their understanding Newtonian motion in these modules.

*The third week*Day 6

1. Inertia experience (45 minutes): Students worked in groups to experience activities such as:

- Pulling a card resting on a cup from under coin resting on the card.
- Spinning a raw egg and a hard boiled egg.
- Pulling the tablecloth out from under the china.

Day 7

1. Impact of impulse and mass on motion (45 minutes): Students worked in group to experience activities such as blowing through a straw at a ping-pong ball to change velocity and measuring acceleration for a ball rolling down a ramp.

Day 8

1. Projectile motion (45 minutes): The teacher did a demonstration for the projectile motion. A ball was released from the top of a track. The ball then fell from the table to the ground. Students predicted and discussed the trajectory of the ball.

Day 9

1. Predict trajectory (45 minutes): In this activity, the students rolled a marble around an aluminum plate with a pie piece cut out and they tracked which way the marble would go.

*The fourth week*Day 10

1. Research project (45 minutes): Module 2 and Module 3 were used in this activity.

Students wrote their hypothesis and research questions according to the handout (Homework 5). Then they used Module 2 and Module 3 to test their research questions and drew their conclusions.

Day 11

1. Continued research projects (45 minutes): Students continued on with their research projects which had not been finished in the previous class period.

*The fifth week*Day 12

1. Roller coaster simulation activity and interview (45 minutes): In this class period, students used a computer program (not included in ThinkerTools package) to measure the speed of a simulated roller coaster. During the class activity, the target students (observed during ThinkerTools activities) and one additional student (randomly selected) were interviewed.

Day 13

1. Project presentations (45 minutes): Students in groups presented their conclusions from their computer experiments and their understanding regarding the concepts of mass and force.

Day 14

1. Posttest (45 minutes): A posttest was given to students after they finished the unit on motion and force.

APPENDIX E. ACCOMPANYING CD-ROM AND RELEVANT TECHNICAL INFORMATION

System requirements for computer disks:

- IBM PC or 100% compatibles with CD-ROM drive; Windows 95 or higher operation system;.
- Macintosh 7200 or higher with CD-ROM drive; 64mb or more memory; Mac OS 8 or higher; etc.

CD-ROM contains data files with sample data sets, ThinkerTools program and modules, and the software needed to open the data files. These files are:

- Student homework questions: Homework.pdf.
- Interview results: Interview Result.pdf.
- Printouts of introductions: Introduction Printouts.pdf.
- Posttest questions: Posttest Questions.pdf.
- Pretest questions: Pretest Questions.pdf.
- Categorized student interactions: Student Interactions.pdf.
- Screenshots of ThinkerTools program modules: TT module screenshots.pdf.
- Adobe Acrobat reader: ar505enu.exe (PC), ar505enu.bin (MAC).
- ThinkerTools program: ThinkerTools68K.bin in the “TT” folder (Mac OS system only).
- ThinkerTools Modules: programs in the “TT” folder (Mac OS system only).

REFERENCES CITED

Andre, T., Hasselhuhn, C., Kreiter, K., Baldwin, W., Leo, C., Miller, T., Mroch, A., Duschen, A., Werner, B., & Akpan, J. P. (2000). Mission Newton! and ThinkerTools: using prior simulations to promote learning about motion. Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans, LA. presented at the Iowa Science Teacher Section Conference, Des Moines, IA.

Blich, B. (1989). Pictorial representation and its cognitive status. Visual Arts Research, 15(1), 29, 68-75.

Bloomer, J. (1974). Prospects for simulation and gaming in mathematics and science education. Programmed Learning and Educational Technology, 11(4), 174-182.

Braun, L. (1972). Digital simulation in education. Journal of Educational Technology Systems, 1(1), 5-27.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. Educational Researcher, 18(1), 32-42.

Carlsen, D. D. & Andre, T. (1992). Use of a microcomputer simulation and conceptual change text to overcome student preconceptions about electric circuits. Journal of Computer-Based Instruction, 19(4), 105-109.

ChanLin, L. & Chan, K. (1996). Computer graphics and metaphorical elaboration for learning science concepts. Annual Meeting of the Association for Educational Communication and Technology. Indianapolis, IN. (ERIC Document ED392390)

Clariana, R. B. (1988). Computer simulations of laboratory experience. Journal of Computers in Mathematics and Science Teaching, 8(2), 14-19.

CTGV (1990). Anchored instruction and its relationship to situated cognition.

Educational Researcher, 19(6), 2-10.

CTGV (1993). Anchored instruction and situated cognition revisited. Educational

Technology, 33(3), 52- 70.

Dale, E. (1969). Audiovisual methods in teaching. New York: Holt, Rinehart, and

Winston, Inc.

Dibble, E. & Shaklee, H. (1992). Graph interpretation: a translation problem? Paper

presented at the Annual Meeting of the American Educational Research Association. San

Francisco, CA.

Ellington, H, Addinall, E, & Percival, F. (1981). Games and simulations in science

education. New York: Nichols Publishing Company.

Fisher, M. A. (1992). Categorization, or schema selection in graph comprehension.

Paper presented at the Annual Meeting of the American Educational Research Association.

San Francisco, CA.

Friel, S. N. & Bright, G. W. (1995). Graph Knowledge: Understanding how students

interpret data using graphs. Paper presented at the Annual Meeting of the North American

Chapter of the International Group for the Psychology of Mathematics Education. Columbus,

OH. (ERIC Document ED391661)

Gorsky, P. & Finegold, M. (1992). Using computer simulations to restructure

students' conceptions of force. Journal of Computers in Mathematics and Science Teaching,

11, 163-178.

Hmelo, C. & Day, R. (1999). Contextualized questioning to scaffold learning from

simulation. Computer & Education, 32, 151-164.

Kelly, P. R. (1997). Transfer of learning from a computer simulation as compared to a laboratory activity. Journal of Educational Technology System, 26(4), 345-351.

Khoo, G. & Koh, T. (1998). Using visualization and simulation tools in tertiary science education. Journal of Computers in Mathematics and Science Teaching, 17(1). 5-20.

Krajcik, H. S., Simmons, P. E., & Lunnetta, V. N. (1988). A research strategy for the dynamic study of students' concepts and problem solving strategies using science software. Journal of Research in Science Teaching, 25, 147-155.

Lunetta, V. N. & Hofstein, A. (1981). Simulations in science education. Science Education, 65(3), 243-52.

Marks, G. H. (1982). Computer simulation in science teaching: an introduction. The Journal of Computers in Mathematics and Science Teaching, 1 (4), 18-20.

Maton, A., Hopkins, J., Johnson, S, and others. (1997). Motion, Forces, and Energy. Englewood Cliffs, N.J.: Prentice Hall.

McGuire, C. (1976). Simulation technique in the teaching and testing of problem-solving skills. Journal of Research in Science Teaching, 13(2), 89-100.

Otero. V. K., Johnson. A, & Goldberg. F. (1999). How does the computer facilitate the development of physics knowledge among prospective elementary teachers?. Journal of Education, 181(2), 57-89.

Paivio, A. (1971). Imagery and verbal processes. New York: Rinehart & Winston.

Paivio, A. (1986). Mental representations: A dual coding approach. New York: Oxford University Press.

Pankuch, B. (1998). Multimedia in lectures and on the world wide web. Issues of Education at Community Colleges: Essays by Fellows in the Mid-Career Fellowship Program at Princeton University. Princeton Univ., NJ. (ERIC Document ED437126)

Peters, H. J. & Daiker, K. C. (1982). Graphics and animation as instructional tools: a case study. Pipeline, 7(1), 11-13

Rieber, L. P. (1990). Using computer animated graphics in science instruction with children. Journal of Educational Psychology, 82(1), 135-40.

Rieber, L. P. (1991). Animation, incidental learning, and continuing motivation. Journal of Educational Psychology, 83(3), 318-328.

Rieber, L. P. & Kini, A. (1995) Using computer simulations in inductive learning strategies with children in science. International Journal of Instructional Media, 22(2), 135-144.

Silverstein, O. & Tamir, P. (1993). The role of imagery in learning biology science through television. Israel. (ERIC Document ED393439)

Van Eck, R. (2000). The effect of advisement and competition on transfer, advisor use, and attitude toward mathematics using a computer-based simulation game. Paper presented at the Annual Meeting of the American Educational Research Association, New Orleans, LA. (ERIC Document ED441668)

Weller, H. G. (1995). Diagnosing and altering three Aristotelian alternative conceptions in dynamics: microcomputer simulations of scientific models. Journal of Research in Science Teaching, 32(3), 271-290

White, B. Y. & Frederiksen, J. R. (1998). Inquiry, modeling, and metacognition: making science accessible to all students. Cognition and Instruction, 16(1). 3-118.

Williamson, V. M. and Abraham M. R. (1995). The effects of computer animation on the particulate mental models of college chemistry students. Journal of Research in Science Teaching, 32(5), 521-34.

Zietsman, A. I. & Hewson, P. W. (1986). Effect of instruction using microcomputer simulations and conceptual change strategies on science learning. Journal of Research in Science Teaching, 23(1), 27-39.

ACKNOWLEDGEMENTS

My thanks are due to my wife Hsueh-Hua Chuang for her support and encouragement. Without her support and understanding, I would have never accomplished this thesis. Special love and thanks must go to my son, Matthew, who was born when I started to work on this thesis and has grown along with this thesis.

I would also like to express my gratitude to Dr. Thomas Andre for his encouragement and inspiration.